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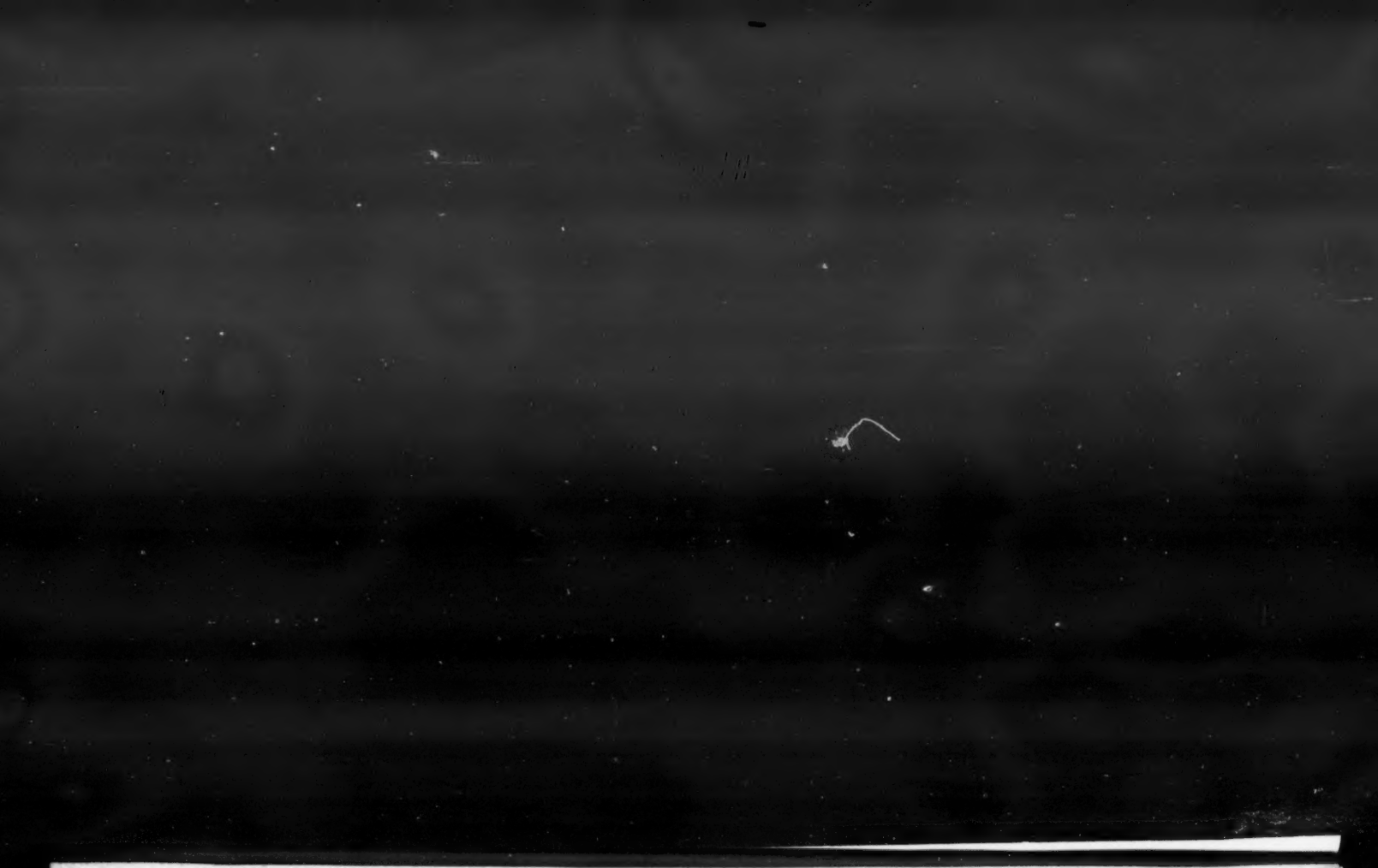


THE

AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

ART. XIII.—*On Certain Astronomical Conditions favorable to Glaciation;* by GEO. F. BECKER.

THE influence of local terrestrial conditions on glaciation is manifest to observers, and few geologists will entertain the idea that cosmical conditions alone can have determined the glacial epoch. Yet variations in the elements of the earth's orbit have certainly influenced climate, and they must have influenced it more favorably to glaciation at some periods than at others. The nature and extent of this influence have been much discussed; but it seems to me that further light can be thrown upon the subject by considering in detail the distribution of solar energy with reference to latitude, and the rate at which this energy is received during the two great seasons separated by the equinoxes.

The elements of the earth's orbit undergo slow variations, and three of these variations affect climate. The time at which the earth is in perihelion affects the length of the two great seasons. If perihelion coincides with either equinox, the seasons are of equal length. If perihelion coincides with either solstice, the seasons differ in length as much as they can for a given eccentricity of the orbit. The whole time which intervenes between the occurrence of seasons of equal length and that of seasons of the most diverse length is five or six thousand years, being the time required for the precession of the equinoxes to amount to a right angle. The eccentricity of the earth's orbit determines the possible difference between the seasons, and it slightly affects the mean distance of the earth from the sun, so that at a period of high eccentricity the world receives a little more heat than it does at a period of

zero eccentricity.* It is mechanically possible for the eccentricity to become zero,† and it is never a large quantity. The latitude of the tropical circles also fluctuates within somewhat narrow limits, and of course the polar circles fluctuate correspondingly. There appear to be no other changes in the orbit which can affect the accumulation of ice, and all of these have been considered before now.

Dr. James Croll, as is well known, attributed the glacial epoch to the more or less indirect action of the difference in the length of the seasons, some 35 days, which occurs when the eccentricity is high.‡ Sir Robert Ball dwells upon the difference in the amount of heat received in the two seasons by an entire hemisphere, and he regards the low rate at which the winter hemisphere receives sunshine when the winter has its greatest length as an explanation of the ice age. This astronomer computed that the proportion of heat received during warm season (irrespective of its length), is expressed by $\frac{1}{2} + \sin\varepsilon/\pi$, where ε is the latitude of the tropical circles, and at present this fraction is expressed numerically by 0·627. Thus at the period of greatest eccentricity three eighths of the entire heat of the year may be spread over a winter some two hundred days in length.§

Sir Robert quotes a passage from Sir John Herschell from which it appears that this famous astronomer, at least momentarily, assumed that each hemisphere would receive the same amount of heat in each of the two great seasons, so that the difference of climate would depend solely on the length of the season.‖ If Herschell was under this impression, the mistake was a temporary one; for a page or two before the passage in which the erroneous statement is found he says:—"Now the temperature of any part of the earth depends mainly on its exposure to the sun's rays. . . . Whenever then the sun remains more than twelve hours above the horizon of any place, and less beneath, the general temperature of that place will be above the average; when the reverse below. As the earth, then, moves from A to B, the days growing longer, and the nights shorter in the northern hemisphere, the temperature of every part of that hemisphere increases and we pass from spring to summer."

This is of course the usual explanation of the seasons to be found in all astronomies and physical geographies. If it were true that a hemisphere received the same amount of heat in

* See the note appended to this paper on the calculation of sunshine per unit area.

† Cf. J. N. Stockwell, Smiths. Cont. to Knowledge, vol. xviii, 1873.

‡ Climate and Time.

§ Cause of the Ice Age, 1892.

‖ Outlines of Astronomy, § 368 (c) in 9th ed. 1867.

each great season, the winter would always be the long season, and therefore winter would occur in both hemispheres at the same time! It appears from the paragraph following that in which the mistake occurs, that Herschell was thinking particularly of tropical climates. Now at the equator it is literally true that the heat received in summer and in winter is the same, as will be shown in the second part of this paper, and the application which Herschell makes of his equal division is to explain the alleged great intensity of summer heat in the tropical regions of Australia as compared with those of northern Africa.

While at or close to the equator the heat received in each season is the same, at the poles all of the heat is received in summer. Hence while it is true that with the present obliquity only about three-eighths of the entire heat received by a hemisphere is received in winter, this fact helps but little towards an explanation of climate. The distribution of heat between the seasons varies with the latitude, and to form any just idea of the effect of eccentricity on climatic conditions one must know the heat received per unit area in any latitude.

The method of finding the amount of sunshine per unit area between equinoxes is very simple in principle. The great circle bounding the illuminated half of the earth is called the circle of illumination, and is represented by the right hand circle in figure 1. Any parallel of latitude projected onto the

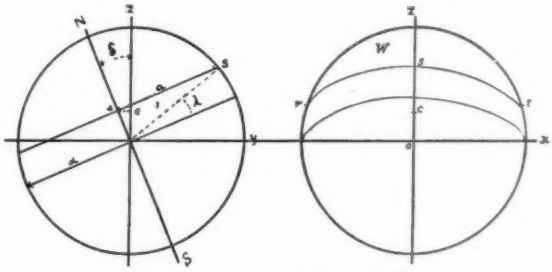


FIGURE 1.—Circle of Illumination.

circle of illumination becomes an ellipse, e. g., the ellipse r, s, t. The heat received between this parallel and the pole while the sun remains in the same position will be proportional to the crescentic area marked W. If one supposes a second parallel very close to the first, say at the unit distance from it, the narrow interval between their projections will be proportional to the heat received upon a zone of the earth's surface. These conditions apply only to an instant of time because the declina-

tion of the sun varies from zero at the equinoxes to 23° 27′ at the solstices. The next step is to find the average area on the circle of illumination representing the projection of the narrow zone from equinox to equinox. When this is accomplished, one has only to multiply the result by the time interval and divide by the length of the parallel of latitude to obtain the area on the circle of illumination representing the solar radiation received per unit area of the earth's surface between the autumnal and the vernal equinoxes. The unit in which radiation is measured may be arbitrarily chosen and as arbitrarily changed, provided that it is employed for all latitudes. I have chosen one which is convenient. It and the formulas for computation are explained in a note appended to this paper.

The heat received per unit area between equinoxes is independent of the length of the season being proportional to the change of the earth's longitude in its orbit.* The average rate at which heat is received during one of the great seasons is therefore merely the total heat per unit area divided by the length of the season.

The radiant energy per unit area depends to a slight extent upon the eccentricity of the orbit. If u_0 is the energy per unit area for zero eccentricity, and u the energy for eccentricity e, then

$$u = \frac{u_0}{\sqrt{1-e^2}}.$$

Though the difference is small, it is perfectly easy to take it into consideration, and this I have done.

At the present time the warm season in the northern hemisphere is approximately 186 days 10 hours long† or 1·0208 times half the year. The eccentricity of the orbit is 0·01677, so that if P is the present mean rate at which sunshine is received per unit area in summer in the northern hemisphere and L the length of the summer‡

$$P = \frac{u_0}{L\sqrt{1-e^2}} = 0{\cdot}97978\ u_0.$$

So too if p is the present winter rate I find

$$p = 1{\cdot}02138\ u_0.$$

* The heat received on the area when the earth is in a given position is directly as the time and inversely as the square of the distance, r, from the sun. In an instant therefore it is proportional to dt/r^2. By Kepler's first law this is equal to $d\vartheta/h$ where ϑ is longitude and h a constant.

† See Nautical Almanac for 1895.

‡ The coefficients are stated to five figures not because they are of themselves of interest to this degree of accuracy, but because in checking the tabulated values the numbers really used should be known.

The exact value of the greatest possible eccentricity of the earth's orbit is somewhat uncertain. It is dependent upon the masses of the planets, and these are not determined with final accuracy. It is not far from 0·07 and I shall assume that it is 0·0745, the value taken by Sir Robert Ball. The greatest possible difference between the seasons occurs when the long season is $(1 + 4e/\pi)$ times half the year; and if X and x are the mean rates of receipt of sunshine during the long and short seasons respectively for greatest eccentricity and greatest difference between seasons in the hemisphere where the winter is long, I find

$$X = 1{\cdot}10788\ u_0$$
$$x = 0{\cdot}91590\ u_0.$$

The values are tabulated below with two other sets of values to be explained presently. The diagrams, figures 2 and 3, show the rates graphically, but before commenting upon the differences between the curves it is desirable to consider how the present distribution of heat-rates is related to climate as known by observation.

No one doubts that temperature is dependent in some manner upon solar radiation, but the phenomena are complicated not only by the transfer of heat from one locality to another through the agency of currents of air and water, but also by the selective absorption of the atmosphere, and it is a question therefore how far the mere receipt of sunshine, or what Humboldt called "the astronomical climate," can be made to explain actual climate. That absorption of radiant energy by the atmosphere affects climate has long been understood. Energy of different wave lengths however is differently absorbed by the same gas, and different gases absorb energy differently; so that the subject is one of great complexity. According to Prof. S. P. Langley,* the temperature of an airless planet, even under a vertical sun, would be little above the freezing point of water; and of course the unilluminated part of such a planet would tend toward the absolute zero. Hence the actual temperature of the earth is determined to a very great extent by selective absorption of the atmosphere. No doubt this has always been the case, and, since the composition of the air must have changed as geological time progressed, it is highly probable that differences in selective absorption have determined, or partly determined the differences in mean tem-

* The Temperature of the Moon. Nat Acad of Sci. vol. iv. part II. 1889, page 193. The conclusion drawn from observations on Mt. Whitney, that an airless planet would fall far short of zero C., is modified in this passage.

perature at different epochs * The glacial epoch is relatively speaking so recent that the composition of dry air was probably much the same then as now; but even moisture affects absorption of heat rays, greatly increasing it, so that relatively moist air tends to become hotter while dry air tends to sink below the average temperature.

It is notorious that climate is enormously affected by oceanic currents, themselves due to winds of prevalent direction, and it would therefore be in vain to seek any very close relation between temperature and solar radiation in littoral areas. On the other hand, in the interior of the continents, where air currents alone distribute the heat received from the sun, it seems possible that a relation may show itself. Considering the facts presented above it seemed to me that a reasonable trial hypothesis would be this:—The average variation of temperature from a certain mean in purely continental areas during a great season may be nearly proportional to the mean rate at which solar energy is received during that season.

In an ideally continental climate the summers will be hotter and the winters will be colder than in any real climate, since the actual tendency is always toward an equalization of temperature. Hence to test the trial hypothesis it is required to know the lowest latitudes to which mean winter isotherms descend in continental areas, and the highest latitudes which mean summer isotherms reach. In this enquiry the lag of heat effects would have to be taken into consideration, so that the seasons for temperature would not be divided by the equinoxes. I do not know of any isothermal charts suitable for the enquiry in this form. The next best material would be charts for the two extreme months, January and July, for though such charts would give temperatures exceeding the means in intensity, these temperatures would probably be proportional to the means. In other words it is probable that the temperature curve for a representative cold winter is derivable from that of a representative warm winter by projection.

Proceeding on this assumption I collected data from Mr. A. Buchan's January and July charts based on the mean observations for eleven years.† The lowest latitudes to which each isotherm descended in January in Asia and in North America were noted and the highest latitudes to which they ascended in July. They are recorded in the following table.

* It is substantially certain that the sun's own heat has varied. The record of its variation must exist in the rocks, but as a palimpsest. The greater equability of the earlier climates seems to me explicable, at present, only by greater atmospheric absorption.

† Encyc. Brit., 9th ed. Art.: Meteorology.

Deg. F. Isotherm.	Lowest January Latitude.		Highest July Latitude.	
	Asia.	N. America.	Asia.	N. America.
−50°	60°	----		
−40	63	----		
−30	59	64		
−20	55	56		
−10	46	52		
0	45	49		
+10	42	47		
20	38	42		
30	36	39		
40	27	34	77	----
50	25	31	72	69
60	21	----	68	66
70	17	----	59	56
80	10	----	48	46
90	----	----	39	43

Some of these temperatures are affected to a greater or less extent by the neighborhood of water as may be seen from the charts. Thus the polar sea must certainly have a cooling effect in Siberia in summer at latitude 77, and 40° must be there somewhat too low a reading for a continental climate in July. Similarly in winter 70° and 80° must be rather higher than the isotherms in winter would be in southern Asia if land continued southward. Again the great elevation of Central Asia and of the Rocky Mountain region must give summer readings lower than would be recorded were these areas at sea-level.

Imperfect as these data are, they seem the best available, and as such they are entered in diagram 2, an arbitrary unit being selected as representing a Fahrenheit degree. Each X represents an Asian observation, and each Y a North American one.

It will be observed that the points representing temperatures lie remarkably close to the curves representing the present rate of receipt of solar energy, and thus seem strongly confirmatory of the trial hypothesis which, it may be well to state, was not framed to fit the temperature observations. A still closer agreement would be obtained by using a somewhat larger unit for temperature. The climate represented by the curves is intentionally shown as somewhat more extreme than the observed climate because such would be the case if the air were immobile. It might be easy to lay too much stress on the close agreement of the curves and temperatures. I desire to draw but one conclusion from it, viz: the mean rate at which sunshine is received per unit area in continental climates is so important an element in determining the seasonal deviation

from the mean temperature, that the curves representing mean rate afford a sound basis for comparison between continental climates for different values of the eccentricity of the earth's orbit or for different values of obliquity of the ecliptic, the composition of the atmosphere and the intensity of solar radiation being supposed constant. This conclusion seems to me fully justified by diagram 2, and it will be assumed in what follows.

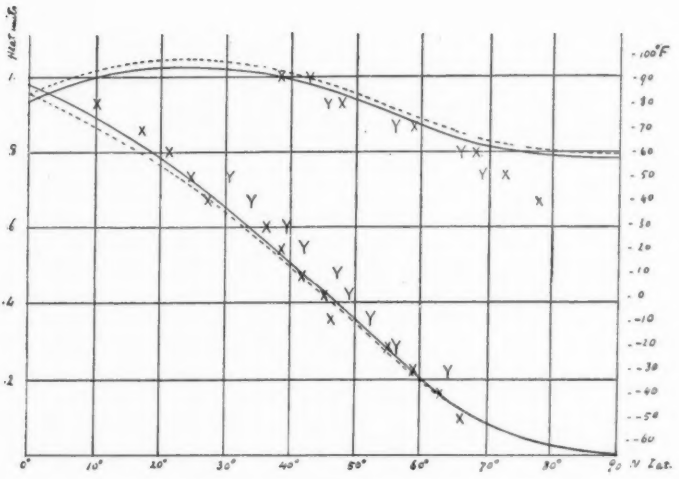


FIGURE 2.

Heat rates for present conditions in each of the great seasons. The rates for zero eccentricity and present obliquity are shown by dotted lines. Points marked X are Asian mean temperatures in January and July. Points marked Y are North American mean temperatures for the same months.

In considering the effect of secular variations of the earth's orbit on the accumulation of ice, certain criteria of climate must be fixed upon. So far as I can see, the conditions prevailing in a glaciated hemisphere should be as follows. The torrid and lower temperate zone, in which evaporation chiefly takes place, should be as warm as is consistent with other conditions; for it must be remembered that the tension of aqueous

Heat-rates for Northern Summer.

Lat.	P	N	X	B
0°	0·9397	0·9592	1·0626	0·9552
10	0·9945	1·0150	1·1245	1·0144
20	1·0216	1·0427	1·1552	1·0457
30	1·0208	1·0419	1·1543	1·0489
40	0·9930	1·0135	1·1229	1·0245
50	0·9411	0·9605	1·0642	0·9762
60	0·8721	0·8901	0·9862	0·9111
A	0·8270	0·8441	0·9352	0·8768
70	0·8115	0·8283	0·9176	0·8587
80	0·7869	0·8032	0·8898	0·8381
90	0·7798	0·7959	0·8818	0·8326

Heat-rates for Northern Winter.

Lat.	*p*	*n*	*x*	*b*
0°	0·9797	0·9592	0·8785	0·9552
10	0·8955	0·8768	0·8030	0·8698
20	0·7869	0·7705	0·7057	0·7610
30	0·6577	0·6439	0·5898	0·6326
40	0·5127	0·5019	0·4597	0·4893
50	0·3583	0·3508	0·3213	0·3384
60	0·2051	0·2009	0·1840	0·1901
A	0·1164	0·1140	0·1044	0·1198
70	0·0821	0·0804	0·0736	0·0764
80	0·0198	0·0194	0·0177	0·0182

P and *p* stand for present obliquity, eccentricity and length of seasons.

N and *n* stand for present obliquity, 23° 27′, and zero eccentricity.

X and *x* stand for present obliquity, eccentricity = 0·0745, and greatest difference of seasons.

B and *b* stand for obliquity = 24°36′ and zero eccentricity.

N, *n*, B and *b* are computed from the formulas developed in the note appended to this paper which P, *p*, X and *x* are derived from N. and *n* as explained in the text. The rates for the southern hemisphere, shown in diagram 3, are identical with those in the northern hemisphere except in the case of greatest eccentricity when they are multiples of those in corresponding northern latitudes.

A represents the latitude of the arctic circle, or 66° 33′ in all cases excepting those of B and *b* for which A = 65° 24′.

vapor increases much more rapidly than temperature* and so also must the rate of evaporation. On the other hand the cold in high latitudes must be great to promote condensation in the form of snow; besides which the temperature gradient should be high or steep because the energy available for wind, and for water currents due to winds, is in direct proportion to the difference of temperature. The great foe to glaciation in summer is rather warm rain than sunshine, for warm rain represents heat transferred from lower latitudes to higher ones. A cer-

* The tension is a function of the temperature, and this function is not linear.

tain amount of sunshine in high latitudes will not seriously diminish the accumulation of névé; for a great part of the winter snowfall has a temperature far below freezing; and in summer, water resulting from superficial melting will freeze again as it percolates through subjacent snow until the entire accumulation of the past winter is raised to the melting point. Such a process is apparently essential to the formation of glacier ice. While a portion of the direct sunshine is harmlessly employed in converting snow to ice, another and very large part will be reflected from the névé fields. Hence it seems to me that the features of a summer climate in a glaciated hemisphere which are most favorable to ice accumulation are cool tropics and a low temperature gradient toward the pole, even if the direct sunshine in very high latitudes must be increased to bring about a dry climate.

It seems proper to begin a comparison between various climates by considering the conditions in opposite hemispheres at any time when the difference of seasons is considerable. Since the total amount of heat received by a hemisphere between equinoxes is wholly independent of the duration of this interval, one hemisphere will then have long cold winters with short hot summers, and the other will have long cool summers and short warm winters. A comparison of curves representing such conditions shows further, that in the genial hemisphere in winter the temperature gradient will be very high and the zone of evaporation very hot, so that the weather will be very wet as well as relatively warm. The summer in the genial hemisphere on the contrary will be cool and not particularly wet. The high winter temperature, and the corresponding brevity of the season in the genial hemisphere would certainly preclude glaciation with the present mean temperature of the globe. Hence in discussing the conditions favorable to glaciation it is needless to consider those in which the winter is shorter than the summer. This is a conclusion upon which, so far as I know, every one is agreed.

A comparison may now be made between the present climates and that which would prevail in both hemispheres were the eccentricity zero, the apparent obliquity of the ecliptic maintaining its present value. The seasons would then be of equal length, and the climate would be intermediate between that of the present time in the two hemispheres. Five or six thousand years ago the seasons were of equal length, and the eccentricity is now and was then so small as to affect the amount of heat received by an insignificant fraction. In fact the earth now receives 1·00014 times as much heat as it would do if the eccentricity were zero. The rates given in the table

and the curves shown in figures 2 and 3, enable one to judge sufficiently of the climate of zero eccentricity. The winter in the northern hemisphere would be a little cooler throughout and the temperature gradient a little smaller. Other things being

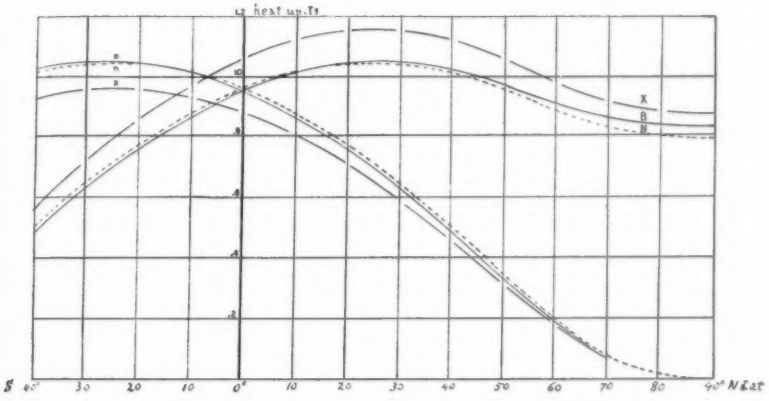


FIGURE 3.

Heat rates for each of the great seasons under various conditions. The curves N and *n* represent the present obliquity and zero eccentricity. They also appear in figure 2. The curves X, and *x* show the rates for greatest eccentricity and winter of maximum length in the northern hemisphere. The curves B and *b* display the rates for an obliquity of 24° 36′ with zero eccentricity.

the same, the winter precipitation would be somewhat smaller, but more of it would fall as snow. In summer the July temperature would be two or three degrees F. higher than it now is, and the heat gradient would almost imperceptibly exceed the present. On the whole the normal weather would probably be within the range of present experience or, in other words, the winter would be what is now considered a cold one, and the summer such as is now thought unusually warm in the northern hemisphere; but the seasons would not be so extreme as they would now be in the southern hemisphere were the distribution of continental areas there the same as it is in the northern hemisphere.

Having established a climate of zero eccentricity it may be compared with the extreme climate of highest eccentricity. It appears from diagram 3 and the table that the winter of the eccentric period in the rigorous hemisphere would be intensely cold as compared with that of the period of zero eccentricity, but it is important to observe that the difference would be most marked in the tropics. It is not needful to depend on my formulas or tabulated values of heat rates to assure oneself

of the general truth of this result. For an increase in the length of the winter diminishes all heat-rates or temperatures in the same proportion; and since the rates are highest in the tropics, the greatest decrease must also take place in the torrid belt. The indications of the diagram are that the temperature of January in the eccentric period would be greatest at the tropic of Capricorn, and that it would there be no warmer than it now is in July at 45° of north latitude. It follows that the evaporation would be very small and that the snowfall in high northern latitudes would be small. The heat gradient during the eccentric winter is also less steep than it is possible to make it by any other combination of conditions, and therefore the winter of this period in the northern hemisphere would be the calmest, dryest and coldest possible.

The summer of the eccentric period in the hemisphere of rigorous climate will be the hottest possible; nearly 20° F. hotter, it would seem, than that of the present time in temperate latitudes. The evaporation would of course be immense. The heat gradient toward the pole is also considerably greater than it now is, or than it would be at the time of zero eccentricity. Hence the summer would be wet as well as hot. It seems to me, then, that the period of greatest eccentricity would be most unfavorable to glaciation, the snowfall being the smallest, and the summer rainfall the largest which can occur with the present obliquity. It seems much less favorable than the period of zero eccentricity when the winter cold is great enough to preclude much rain in the higher portion of the temperate zone, while the temperature in the tropics is great enough to produce active evaporation. It would be manifestly absurd to suppose equality of seasons sufficient to produce an ice age; but I am forced to the conclusion that, so far as eccentricity is concerned in the matter at all, the smaller the eccentricity the more favorable are the conditions for glaciation.

Thus far only a slight reference has been made to the variation of the obliquity. Its influence on glaciation has been considered by various authors, and Dr. Croll attributes to a greater obliquity a considerable influence on the temperature of the arctic circle. The greatest possible obliquity of the apparent ecliptic is believed to be 24° 36′, and I have adopted this value for computation.* The heat-rates are recorded in the table, and the corresponding curves are shown in figure 3.

At first sight the winter curve of the period of greatest obliquity seems practically undistinguishable from that for the present obliquity, the eccentricities being in both cases zero.

* Stockwell gives as the greatest obliquity 24° 35′ 57″·53 for the values of the masses of the planets which he adopts. Smiths. Cont., vol. xviii, 1873, p. 175.

There is a difference however of considerable importance. In either case the maximum mean rate of receipt of sunshine, or the maximum temperature during the northern winter, is at the Tropic of Capricorn and it is from the maximum that the winds laden with moisture will blow toward either pole.* Now when the obliquity was 1° 9′ greater than it now is, the Tropic of Capricorn was so much further south, and the area to the north of this tropic was about 1,800,000 square miles greater than that north of the corresponding parallel to-day. This area is somewhat greater than the sum of the areas of the Mediterranean Sea and the Gulf of Mexico. The gradient northward in winter was almost exactly what it is to-day, the temperature was lower throughout, though not more than a few degrees; but this was compensated for, more or less completely, by the increased area of evaporation supplying precipitation to high northern latitudes. It would appear therefore that the precipitation may have been as great as it now is, but that a larger part of the precipitation must have been snow.

In summer at high obliquity the zone of evaporation was 1,800,000 square miles less than it now is, and the temperature gradient toward the pole was smaller than any other, smaller even than that of the summer in the genial hemisphere of the period of highest eccentricity. Hence it was perhaps the dryest possible summer. Its temperature was somewhat below that of the present time in the southern hemisphere from the equator to latitude 45°. Beyond this point it was a little higher but, as has been pointed out, dry summer heat in very high latitudes cannot greatly diminish the accumulation of snow.

I began this enquiry without the remotest idea as to what conclusion would be reached. At the end of it I feel compelled to assert that the combination of low eccentricity and high obliquity will promote the accumulation of glacial ice in high latitudes more than any other set of circumstances pertaining to the earth's orbit. It seems to me that the glacial age may be due to these conditions in combination with a favorable disposition of land and water. This theory implies, or rather does not exclude simultaneous glaciation in both hemispheres. It does not imply that the ice age should last only ten or twelve thousand years. If the conditions here suggested are correct, variations in the disposition of land and water may have determined intervals of glaciation, not necessarily the same ones in New England and the basin of the Mississippi; and there may have been considerable time dif-

* It is well known that the July and January winds blow across the equator. This tendency is strongest in July because of the greater land area of the northern hemisphere.

ferences in the inception or the cessation of glaciation in various regions. It is not needful to assume that the glaciation of the Sierra Nevada either began or ended synchronously with the ice age in New England.

The date at which a minimum of eccentricity last coincided with a maximum of obliquity can almost certainly be determined. According to Stockwell the obliquity has been diminishing for the past 8000 years and was within 21 minutes of its maximum value at the beginning of that time. According to Leverrier the eccentricity passed through a minimum 40,000 years ago, the value being then about two-thirds of the present one. So far as I know the obliquity has not been computed beyond 8000. This can of course be done for Stockwell's value of the masses of the planets, or for newer or better ones. All the indications seem to be that within thirty or forty thousand years conditions have occurred and have persisted for a considerable number of thousand years which would favor glaciation on the theory of this paper. It is conceivable that very remote coincidences of high obliquity and low eccentricity might be determined, answering perhaps to glaciation in the Paleozoic; but until some simple law governing the periodicity of secular variations is discovered such a result is not to be looked for; it is at present practicable to formulate the variations only by omitting terms above a certain order and exterpolation beyond a few score thousand years is consequently untrustworthy.

Calculation of Sunshine per unit area.

The following note explains the method of finding the amount of solar energy received per unit area of the earth's surface in any latitude between equinoxes, the ellipticity of the earth being ignored. Mr. L. W. Meech has already solved the very similar problem of finding the heat received per unit area for the entire year, and it is possible to develop from his formulas those applicable to the present purpose; but this would take nearly as much space as a fresh presentation. Mr. Meech's method of dealing with the subject is also quite different from that here presented, which I worked out before making acquaintance with his admirable memoir.*

When the sun's declination is δ, any parallel in latitude λ will be projected onto the circle of illumination as an elliptical arc dividing the circle into two unequal portions. If λ and δ have opposite signs, the smaller of these areas will be a crescent which I shall call W. To find the area W shown in diagram 1, let a be the earth's radius, a and b the semiaxes of

* Smithsonian Contr. to Knowledge, vol. ix, 1857.

the ellipse into which the parallel of λ is projected, x and z the coördinates of the point t at which the ellipse meets the great circle in the projection, c the center of the ellipse, e the center of the small circle which is projected into the ellipse. Then it is easily seen from the diagram that

$$a = \alpha \cos \lambda\,;\; b = \alpha \cos \lambda \sin \delta\,;\; c = e \cos \delta = \alpha \sin \lambda \cos \delta\,;$$

$$z = \frac{\alpha \sin \lambda}{\cos \delta}\,;\; x = \sqrt{\alpha^2 - z^2} = \frac{\alpha \cos \lambda}{\cos \delta}\sqrt{1 - \frac{\sin^2 \delta}{\cos^2 \lambda}}$$

The area of the circular segment r, z, t is $\alpha^2 \sin^{[-1]}\frac{x}{\alpha} - xz$ and that of the elliptical segment r, s, t is $ab \sin^{[-1]}\frac{x}{a} - xz + xc$. The difference is the area sought or

$$W = \alpha^2 \sin^{[-1]}\frac{x}{\alpha} - ab \sin^{[-1]}\frac{x}{a} - xc$$

The arc whose sine is x/a is the sun's semidiurnal arc. Its value in the cold season may be called for brevity X. In the warm season at the same point its value will be π–X. If ϑ is the earth's longitude in its orbit and if ε is the apparent obliquity of the ecliptic it is easy to see and perfectly well known that

$$\sin \delta = \sin \varepsilon \sin \vartheta$$

and this value is to be substituted in that of W. It is also convenient to employ the abbreviation

$$\Delta(\vartheta) = \sqrt{1 - \frac{\sin^2 \varepsilon}{\cos^2 \lambda} \sin^2 \vartheta},$$

so that the semidiurnal arc is

$$X = \text{arc sin} \frac{\Delta(\vartheta)}{\sqrt{1 - \sin^2 \varepsilon \sin^2 \vartheta}}.$$

The value of W may now be written

$$W = \alpha^2 \{\sin^{[-1]}(\cos \lambda \sin X) - \cos^2 \lambda \sin \varepsilon \sin \vartheta . X - \sin \lambda \cos \lambda \Delta(\vartheta)\},$$

and when λ increases W decreases; so that the rate of increase of W, or the area on the circle of illumination occupied by the projection of a zone of unit width in the cold season, is represented by

$$-\frac{dW}{d\lambda} = \alpha^2 \sin 2\lambda \{\cot \lambda \Delta(\vartheta) - \sin \varepsilon \sin \vartheta . X\}.$$

Let the amount of sunshine received upon the unit area at the unit distance from the sun in the unit of time be H. Then in an instant of time the amount received upon the zone of unit width at a distance r from the sun would be

$$\frac{-dW}{d\lambda}\cdot\frac{H}{r^2}\,dt.$$

By the principle of the conservation of the moment of momenta, the radius vector of an unperturbed planet sweeps over equal areas in equal times. If h is a constant this, which is one of Kepler's laws, is expressed by $r^2d\vartheta = hdt$. By substitution in the last expression this gives the following measure of the receipt of solar energy for a small change in the earth's longitude,

$$-\frac{dW}{d\lambda}\frac{H}{h}d\Im = \frac{H\alpha^2\sin 2\lambda}{h}\{\cot\lambda\,\Delta(\Im)-\sin\varepsilon\sin\Im.\,X\}d\Im \quad (1)$$

and the whole heat received between the autumnal and the vernal equinoxes on a zone of unit width will be proportional to the integral of this quantity from $\vartheta = 0$ to $\vartheta = \pi$, or to twice the integral from zero to $\pi/2$, since the conditions are symmetrical. To find the corresponding value for the summer interval it is only necessary to substitute π–X for X.

To facilitate integration it may be noted that

$$\sin\Im\,.\,X\,.\,d\Im = \cos\Im\,dX - d(X\,.\cos\Im)$$

and

$$\frac{dX}{d\Im} = -\frac{\sin\varepsilon\cos\Im\tan\lambda}{(1-\sin^2\varepsilon\sin^2\Im)\Delta(\Im)}$$

These values reduce (1) to

$$-\frac{dW}{d\lambda}\frac{H}{h}d\Im = \frac{H\alpha^2}{h}\sin 2\lambda\left\{\cot\lambda\,\Delta(\Im) + \tan\lambda\left(\frac{1}{\Delta(\Im)}-\frac{\cos^2\varepsilon}{(1-\sin^2\varepsilon\sin^2\Im)\Delta(\Im)}\right)+\frac{d}{d\Im}\left(X.\cos\Im\sin\varepsilon\right)\right\}d\Im. \quad (2)$$

For values of λ from 0 to $\pi/2-\varepsilon$, or from the equator to the polar circle, this is integrable term by term. If $\sin\varepsilon/\cos\lambda = \varkappa$ and if $E^1(\varkappa)$, $F^1(\varkappa)$, $\Pi^1(\varkappa)$ denote complete elliptic integrals of the three classes for the modulus $\varkappa$; and if Z is the integral of (2), being the solar radiation received between equinoxes on the zone of unit width,

$$Z = \frac{2H\alpha^2}{h}\sin 2\lambda\left\{\cot\lambda\,E^1(\varkappa) + \tan\lambda[F^1(\varkappa)-\cos^2\varepsilon\,\Pi^1(\varkappa)] \pm\frac{\pi}{2}\sin\varepsilon\right\}. \quad (3)$$

the plus sign giving the value for summer and the minus sign that for winter.

At the equator, or for $\lambda = 0$, (3) reduces to the term containing $E^1(\varkappa)$. At the polar circle Z ceases to be doubly periodic; for then $\Delta(\vartheta)$ degenerates into $\cos\vartheta$ and $\cos\lambda = \sin\varepsilon$ so that

$$\frac{dX}{d\Im} = -\frac{\cos\varepsilon}{1-\sin^2\varepsilon\sin^2\Im}.$$

These relations also reduce (1) to an integrable form and give for this one latitude

$$Z = 2\frac{H\alpha^2}{h}\sin 2\varepsilon\left\{\tan\varepsilon + \cos\varepsilon\, ln\cot\frac{\pi/2-\varepsilon}{2} \pm \frac{\pi}{2}\sin 2\right\}$$

Within the polar circle the limits of integration change, because for a part of the time there is no illumination. Furthermore $\sin\varepsilon/\cos\lambda > 1$, and a transformation is needful to reduce the functions to standard forms. To effect this let

$$\frac{\sin\varepsilon\sin\Im}{\cos\lambda} = \sin\varphi, \text{ and } \frac{\cos\lambda}{\sin\varepsilon} = \mu < 1.$$

Then

$$\varkappa = 1/\mu;\ \Delta(\Im) = \cos\varphi;\ \cos\Im = \sqrt{1-\mu^2\sin^2\varphi} = \Delta(\varphi);$$
$$d\Im = \frac{\mu\cos\varphi\, d\varphi}{\Delta(\varphi)}.$$

The superior limit of integration is given by

$$\Delta(\Im) = 0 \text{ or } \varphi = \pi/2.$$

By these substitutions (2) becomes*

$$-\frac{d\,W}{d\lambda}\frac{H}{h}d\Im = \frac{H\alpha^2}{h}\sin 2\lambda\left\{\frac{\sin\varepsilon}{\sin\lambda}\Delta(\varphi) + \frac{\cos\varepsilon}{\tan\varepsilon\sin\lambda}\cdot\frac{1}{\Delta(\varphi)}\right.$$
$$\left.-\sin\lambda\frac{\cos\varepsilon}{\tan\varepsilon}\frac{1}{(1-\cos^2\lambda\sin^2\varphi)\Delta(\varphi)} + \frac{d}{d\varphi}(\sin\varepsilon\,\Delta(\varphi).X)\right\}d\varphi,$$

and this when integrated from zero to π is

$$Z = 2\frac{H\alpha^2}{h}\sin 2\lambda\left\{\frac{\sin\varepsilon}{\sin\lambda}E^1(\mu) + \frac{\cos\varepsilon F^1(\mu)}{\tan\varepsilon\sin\lambda} - \frac{\sin\lambda\cos\varepsilon}{\tan\varepsilon}\Pi^1(\mu)\right.$$
$$\left.\pm\frac{\pi}{2}\sin\varepsilon\right\}.$$

Knowing the zonal receipt of solar energy for any and every latitude, the heat per unit area is within reach; for the length of a parallel of latitude is $2\pi a\cos\lambda$, and if u is the sunshine per unit area for the interequinoctial period

* In testing the truth of this formula it is convenient to remember that
$$\frac{\cos^2\phi}{\Delta(\phi)} = \frac{\Delta(\phi) - (1-\mu^2)/\Delta(\phi)}{\mu^2}.$$

$$u = \mathrm{Z}/2\pi\alpha \cos \lambda.$$

At the equator this becomes

$$u = 2\,\frac{\mathrm{H}\alpha}{\pi h}\,\mathrm{E}^1(\varkappa);$$

$\mathrm{E}^1(\varkappa)$ being in this case the quadrant of an ellipse the numerical eccentricity of which is $\sin \varepsilon$. The quantity h is a function of the sum of the masses of the sun and earth, say m, the major semiaxis of the earth's orbit, A, and the eccentricity, e, in fact

$$h^2 = Am\,(1 - e^2).$$

Now the major axis of a planet's orbit has until lately been assumed to be absolutely constant. In 1879, Mr. D. Eginitis showed that a surmise of Tisserand's was correct, and that the major axis is subject to a secular inequality of the third order with respect to the masses.* For most purposes, however, this minute change is negligible as well as the increment of mass due to the accumulation of meteoric matter. Hence e may be regarded as the only variable in the value of h. If the obliquity were zero and the eccentricity were zero, so that the orbit would be a circle of radius A, its plane also coinciding with that of the equator, $\mathrm{E}^1(\varkappa)$ would reduce to $\pi/2$, and the solar energy received between equinoxes at the equator would be

$$u = \frac{\mathrm{H}\alpha}{\sqrt{Am}}.$$

Now the unit in which radiant energy is measured is arbitrary; this last value is a convenient unit and I have adopted it.

For computation it is desirable to reduce the elliptic integral of the third class to integrals of the first and second classes. This is possible by a well known theorem which applied to $\Pi^1(\varkappa)$ and $\Pi^1(\mu)$ gives

$$\Pi^1(\varkappa) = \Pi\left(\varkappa, \sin \varepsilon, \frac{\pi}{2}\right) = \mathrm{F}^1(\varkappa) + \frac{\cot \lambda}{\cos \varepsilon}\left\{\mathrm{F}^1(\varkappa)\,\mathrm{E}\left(\varkappa, \frac{\pi - 2\varepsilon}{2}\right)\right.$$
$$\left. - \mathrm{E}^1(\varkappa)\,\mathrm{F}\left(\varkappa, \frac{\pi - 2\varepsilon}{2}\right)\right\}$$

E and F denoting integrals of amplitude less than $\pi/2$, and

$$\Pi^1(\mu) = \Pi\left(\mu, \cos \lambda, \frac{\pi}{2}\right) = \mathrm{F}^1(\mu) + \frac{\tan \varepsilon}{\sin \lambda}\left\{\mathrm{F}^1(\mu)\,\mathrm{E}(\mu, \varepsilon)\right.$$
$$\left. - \mathrm{E}^1(\mu)\,\mathrm{F}(\mu, \varepsilon)\right\}.$$

* Ann. Observ. Paris. Mém. vol. xix, 1889, paper H.

Substitution of these values in $Z\,2\pi a \cos\lambda$ gives the following expressions for actual use:—

At the equator the modulus is $\sin\varepsilon$ and for either season alike

$$u = \frac{2\,E'}{\pi\sqrt{1-e^2}}.$$

From the equator to the polar circle the modulus is $\sin\varepsilon \cos\lambda$ and the sunshine per unit area between equinoxes is

$$u = 2\,\frac{\sin\lambda}{\pi\sqrt{1-e^2}}\left\{ E'\cos\varepsilon\left[\frac{\cot\lambda}{\cos\varepsilon} + F\,(90^\circ - \lambda)\right]\right.$$
$$\left. - F'\cos\varepsilon\left[E\,(90^\circ - \lambda) - \tan\lambda\tan\varepsilon\sin\varepsilon\right] \pm \frac{\pi}{2}\sin\varepsilon\right\}.$$

At the polar circle

$$u = 2\,\frac{\cos\varepsilon}{\pi\sqrt{1-e^2}}\left\{\tan\varepsilon + \cos\varepsilon\, ln\cot\frac{90^\circ-\varepsilon}{2} \pm \frac{\pi}{2}\sin\varepsilon\right\}$$

From the polar circle to the pole the modulus is $\cos\lambda / \sin\varepsilon$ and

$$u = 2\,\frac{\sin\lambda}{\pi\sqrt{1-e^2}}\left\{ E'\cos\varepsilon\left[F(\varepsilon) + \frac{\tan\varepsilon}{\sin\lambda}\right] - F'\cos\varepsilon\left[E(\varepsilon)\right.\right.$$
$$\left.\left. - \frac{\cos\lambda}{\tan\varepsilon\tan\lambda}\right] \pm \frac{\pi}{2}\sin\varepsilon\right\};$$

and at the pole this reduces to

$$u = \frac{1}{\sqrt{1-e^2}}\left\{\sin\varepsilon \pm \sin\varepsilon\right\}$$

These formulas can be computed from known series or by the help of Legendre's tables. For $\varepsilon = 23^\circ\ 27'$ I have computed the values tabulated in both ways with coincident results. For $\varepsilon = 24^\circ\ 36'$ I used the tables and checked by differences with the other series. The radiant energy received during the entire year is of course the sum of the energy received during the two seasons. The quantities thus found and multiplied by a constant coincide with Meech's values to four significant figures. Meech took the apparent obliquity at 23° 28′, and the sine of this angle is 1·0007 the sine of 23° 27′, so that a closer correspondence could not be expected.* I have stated my results to four decimals, though for the purposes of this paper three would have been ample.

It need scarcely be mentioned that the effect of the real ellipticity of the meridian is to reduce the receipt of solar energy towards the the poles by a trifling amount.

Washington, D. C., June, 1894.

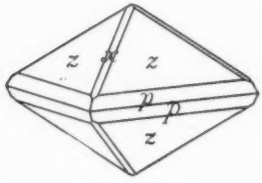
* The obliquity was 23° 27′ 30″ in 1852, or after Meech had begun his investigation. It is now about 23° 27′ 11″.

Art. XIV.—*Mineralogical Notes;* by S. L. Penfield.

1. *Octahedrite from Magnet Cove, Arkansas.*

Up to the present time octahedrite has been found in the United States at only a few places. It is interesting, therefore, to record its occurrence at a new locality, especially as it is one which is noted for the two other forms of titanic oxide, brookite and rutile. While examining the stock of minerals of Dr. A. E. Foote of Philadelphia, Pa., one specimen was found, among a lot of brookites from Magnet Cove, which attracted the writer's attention from its unusual crystalline form. On measuring the crystals they were found to be tetragonal and to have the angles of octahedrite. The habit is shown in fig. 1, the forms being:

1.



p, 111, 1 z, 113, $\frac{1}{3}$ x, 103, $\frac{1}{3}$-i

The reflections of the signal were fairly good and the angles which were measured agree very well with those calculated from the length of the vertical axis as given by Miller,* $\dot{c} = 1{\cdot}7771$.

	Measured.	Calculated.		Measured.	Calculated.
$p \wedge p'$, $111 \wedge \bar{1}11 =$	82° 6′	82° 9′	$z \wedge z'$, $113 \wedge \bar{1}13 =$	53° 54′	54° 1′
$p' \wedge p''$, $\bar{1}11 \wedge \bar{1}\bar{1}1 =$	82 12	"	$z' \wedge z''$, $\bar{1}13 \wedge \bar{1}\bar{1}3 =$	53 49	"
$p \wedge p^{iv}$, $111 \wedge 11\bar{1} =$	43 22	43 24	$z \wedge z^{iv}$, $113 \wedge 11\bar{3} =$	100 20	100 5½

The crystals are black and have a fine metallic luster. The largest are about 5^{mm} in axial diameter. They are implanted upon a white saccharoidal albite, showing small, distinct crystals of albite in the cavities. When tested with salt of phosphorus before the blowpipe they gave the reaction for titanium.

Although a careful search was made, only this one specimen was found, which is now in the collection of Prof. Geo. J. Brush. There can be no doubt about its having come from Magnet Cove, as it resembles in its character and association other specimens from there and also shows a few brookite crystals.

2. *On the Crystallization of Penfieldite.*

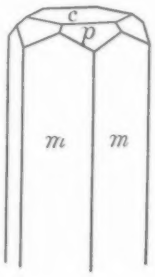
In the September number of this Journal, 1892, page 260, my friend, the late Prof. F. A. Genth, described a new min-

* Mineralogy, 1852, p. 229.

eral from Laurion, Greece, of the composition $PbO \cdot 2PbCl_2$, which he named after the writer. This was one of the last papers published by Prof. Genth and the last new mineral species described by him.

All of the specimens in Prof. Genth's possession were sent to the writer for crystallographic study. As described by him, the crystallization is hexagonal. No indications of hemihedrism were observed. The usual combination is that of prism *m* with basal plane *c*. A few of the crystals showed a pyramid of the second order *p*, $11\bar{2}2$, 1–2, in combination with prism and base, fig. 2. On one small crystal, which gave fair reflections from three of the pyramidal faces, the following measurements of $c \wedge p$ were made, 41° 53′, 41° 52′ and 41° 55′. Taking 41° 53′ as fundamental the axial ratio becomes $a : c = 1 : 0{\cdot}8967$.

2.



Some specimens showed the prismatic faces in combination with steep pyramids of the first order. These were in oscillatory combination, giving rise to horizontal striations and often causing the crystals to taper to a point. The reflections from these pyramids were numerous and so uncertain that no definite symbols could be assigned to them.

The cleavage is distinct parallel to the base and sections show in polarized light a normal interference figure. The double refraction is positive and about as strong as that of calcite.

3. *On the cleavage and parting Planes of Oligoclase and Albite.*

In the November number of this Journal, 1888, page 324, the writer described a very clear glassy feldspar from the Hawk mica mine, near Bakersville, Mitchell Co., N. C., which seemed to show abnormal optical properties. It is found as cleavage masses without crystal faces at a considerable depth in the mine. An analysis by Mr. E. S. Sperry showed that it contained the albite and anorthite molecules in the proportion of $3{\cdot}6 : 1$ and was to be classified therefore as oligoclase. The material that was used for the investigation was a single specimen from the collection of Mr. Norman Spang of Etna, Pa. This was without twinning striations and presented a perfect cleavage parallel to the basal, and an imperfect one, supposed to be parallel to the brachy-pinacoid (010). Plates parallel to this second cleavage showed in convergent polarized light an optical axis almost in the center of the field, while

basal sections gave with the polarizing microscope extinctions inclined about 38°–40° from the edge formed by the meeting of the two cleavages. These optical relations seemed entirely unlike those of oligoclase and the material was therefore described as abnormal. Offret* has since shown that the Bakersville oligoclase has normal optical properties and, therefore, in order to reconcile these differences and to make a further study of the material a new supply was secured from Mr. Geo. F. Kunz of New York and Mr. W. Vance Brown of Plum Tree, N. C., to whom the author's sincere thanks are due. Among the specimens some pieces presented the normal cleavage, polysynthetic twinning and optical properties of oligoclase. Some, however, that were clear and free from twinning, showed the abnormal properties as previously described, but from the examination of a number of fragments it was soon discovered that the second cleavage is not parallel to (010) and that the feldspar thus presents an unusual and unexpected cleavage or parting instead of abnormal optical properties.

In oligoclase the angle γ, between the $\breve{a}$ and $\bar{b}$ axes is practically 90° and the extinction direction on basal sections is +1° or almost parallel to the $\breve{a}$ axis, hence it follows that the angle of 38°–40° which the cleavage makes with the axis of greatest elasticity in a basal section serves to orient the cleavage with reference to the lateral axes. From the measurements of vom Rath† it has been calculated that the pyramid $(\bar{1}\bar{2}1)$ makes angles of 92° 35′ $=(001 \wedge \bar{1}\bar{2}1)$ and 87° 25′ with the base, the measurement of the abnormal cleavage being about 88°, and that the trace of the pyramid on the base intersects the edge between (001) and (010), or the direction of the $\breve{a}$ axis at an angle of 38° 1′, about corresponding to the extinction direction. Exact measurements cannot be made for determining the position of this peculiar cleavage, owing to the poor reflection which it gives and the absence of other planes except the basal cleavage, but it is distinctly parallel to a pyramid and the form $(\bar{1}\bar{2}1)$ has the position to yield all of the abnormal properties that were observed. This abnormal cleavage is well shown on many of the specimens and whether it is a true cleavage or a parting of secondary origin, produced perhaps by pressure, is uncertain but it is probably the latter. The forms that can be broken out, bounded by the basal and abnormal cleavages and an irregular fracture inclined to the base at an angle about equal to β of the feldspars, look like ordinary cleavage blocks of feldspar, and thus caused the

* Bull. Soc. Min. de France, xiii, p. 648, 1890.

† Pogg. Ann., cxxxviii, p. 464, 1869. Also Dana's Mineralogy, Sixth edition, p. 332.

original error in the orientation. Another surprising and unexpected peculiarity of this feldspar is the difficulty of producing the cleavage parallel to (010). Among the specimens that show the unusual pyramidal parting there is not one that shows the (010) cleavage. Some are broken so that the fracture runs nearly parallel to (010) but they present only the curved surfaces of a conchoidal fracture. When the direction of (010) is known, which can be determined by the extinction, it is difficult to produce the cleavage by striking the blocks in a favorable direction with the peen of a hammer, or by striking on a knife blade or chisel whose edge is placed on the crystal in the direction of the desired cleavage. On specimens which show the usual poly-synthetic twinning striæ on the base the (010) cleavage can always be readily obtained. This has given rise to the query, is the good cleavage on plagioclase parallel to (010) only apparent, and is it not possibly the result of a separation along the plane of twinning? Certainly those feldspars which show well developed poly-synthetic twinning readily yield good cleavage surfaces, while those showing no twinning, which the writer has been able to examine, usually yield the (010) cleavage only with difficulty, so that it might well be designated as rather poor and interrupted.

In experimenting upon the cleavages of albite the following peculiarities were also observed. The specimen examined was a large crystal from Amelia, Va., associated with quartz and muscovite. It presented a combination of twinning according to the Carlsbad and albite laws, similar to fig. 7, page 328 of the sixth edition of Dana's Mineralogy, and measured over 70^{mm} in the direction of the $\breve{a}$ and $\dot{c}$ axes. Two of the twinning individuals were fully 6^{mm} broad, measured at right angles to the twinning plane; they were clear and glassy, and free from cracks and poly-synthetic twin lamellæ. The crystal was firmly united by the pinacoid (010) to the quartz and when fragments were detached by striking with a hammer they were always bounded by the basal cleavage and surfaces parallel to the prism $m(110)$ and the pyramid $o(\bar{1}\bar{1}1)$. These latter surfaces had the appearance of perfect cleavages, and often their presence was revealed by cracks, running wholly or partly across the detached fragments. The following measurements were obtained on the reflecting goniometer, the reflections, especially those from m, being sharp and well defined:

$c \wedge m$, $001 \wedge 110 = 65° 10'$ mean of five independent measurements, varying from 65° 7′–65° 12′.

$c \wedge o$, $001 \wedge \bar{1}\bar{1}1 = 57° 50'$ and $57° 33\frac{1}{2}'$.

The calculated angles taken from Dana's Mineralogy are $c \wedge m = 65° 17'$ and $c \wedge o = 57° 49'$. The parting parallel to m was moreover observed at a number of places on the specimen where the latter had been broken. Subsequent attempts to produce surfaces parallel to these same planes by breaking up the detached fragments with a hammer, using the customary devices for obtaining cleavage in definite directions, utterly failed. In other words, the partings parallel to m and o do not have the properties of true cleavage. They seem to be partings along definite cracks within the crystal or they were produced by the peculiar strain to which the fragments were subjected in breaking away from the attachment of quartz. The partings parallel to (110) and $(\bar{1}\bar{1}1)$ were readily produced on this material by pressure in the direction of the $\bar{b}$ axis, the blocks of feldspar being held between plates of lead and squeezed in a vice. As shown by Lehmann* a parting parallel to (110) results from the contraction due to sudden cooling, when heated fragments of albite are thrown into water. A similar result was obtained by the writer but no parting parallel to $(\bar{1}\bar{1}1)$ was observed.

Tests made by pressing the Bakersville oligoclase, and by contraction from sudden cooling, did not yield flat surfaces that could be referred to definite crystal directions.

In conclusion, therefore, it should be emphasized that the cohesion relations of the plagioclase feldspars may show considerable variation. The basal cleavage is always perfect. That parallel to the brachy-pinacoid (010) is usually distinct, while it is sometimes imperfect and hard to produce and especially when poly-synthetic twin lamellæ are absent. Under certain conditions of pressure or tension, partings may occur parallel to the prism $m(110)$ or the pyramid $(\bar{1}\bar{1}1)$ which resemble perfect cleavages, while, as in the case of the Bakersville oligoclase the partings may run in other directions resembling imperfect or interrupted cleavages.

Laboratory of Mineralogy and Petrography,
Sheffield Scientific School, February, 1894.

* Zeitschr. Kryst., xi, p. 612, 1886.

Art. XV.—*Development of the Lungs of Spiders;* by Orville L. Simmons. (With Plate VIII.)

Although several persons* had suggested the close affinity of the Arachnids and Limulus, it was not until the appearance of Lankester's paper, "Limulus an Arachnid" ('81[b]) that the view of such a relationship came into prominence. Since that date it has attracted more and more numerous advocates until now the majority of the special students of Arachnids and Xiphosures recognize the close relationships of the two groups. One of the special homologies insisted upon by Lankester was that existing between the lungs of the Arachnids and the gills of Limulus. But to explain the differences between these organs—the one being an internal air-breathing structure, the other an external apparatus for aquatic respiration—several hypotheses have been advanced, all based upon conditions existing in the adult.

At first Lankester evidently shared the common view that tracheæ were homologous structures throughout the Arthropoda, and so he sought for traces of them in Limulus. In his article "On stigmata in the King Crab" ('81[a]) he announced that he had found traces of stigmata. The position of insertion of each thoracico-abdominal muscle is marked by a deep funnel-like depression of the integument, which from the external surface appears as a stigma.

Later, in his paper "Limulus an Arachnid" ('81[b]) he formulates an hypothesis to show how the gills of Limulus and the lungs of Scorpio (taken because more primitive than Spiders) could have been derived from a common ancestor which he describes as being an aquatic form, breathing by book-like gills. To derive Limulus from such a form would involve only a few changes in dimensions and other unimportant points. To obtain the condition occurring in Scorpio, he assumes that the cup-like depressions behind the appendages, as seen in Thelyphonus, became deeper and larger, finally engulfing the whole appendage. The walls then gradually extended over the cavity, leaving only a slit for communication with the exterior. As change of habits went on this slit was closed up and another slit, still within the area formed by the closure of the primitive opening of the cave of invagination, was formed. Air would enter by this slit, where in Limulus and the early Scorpion ancestors there was blood space. Thus a blood space has been changed to an air space. In the same way an air space (that of the investing sac) has

* Strauss-Durckheim (teste Lankester), van Beneden ('70).

been converted into a blood space. The atropy of the muscles which move the gills in Limulus and similar forms was considered very essential to this theory. The difficulties involved in the changes of blood and air spaces were so considerable as to prevent the acceptance of this hypothesis.

Later, Lankester ('85) put forth a new theory. Because of discoveries concerning the muscles (veno pericardiac) of Scorpio, as well as on account of the insuperable difficulties of his previous view, he gave up his old and advanced a new hypothesis. In the latter the common ancestor is assumed to have had six pairs of mesosomatic appendages, of which five were lamelligerous. These latter in Scorpio became smaller and served only for respiratory organs, soon becoming air-breathing. The four hinder pairs took a "trick" of growth, viz: an invagination of the appendages, beginning at their distal ends, so that they grew into the Scorpion's body, turning their outside in, just as a glove may be turned wrongside out, beginning at the ends of the fingers. Thus the appendages would be tucked into the blood sinus instead of growing out normally. The blood sinus would become a venous sac around the appendage. He explains the "trick" of growth by the least resistance theory—the pressure being exerted on the embryo before it leaves the mother.

J. MacLeod ('82 and '84) sets forth an hypothesis by which he develops Scorpions and similar forms from a Limulus-like ancestor. His first proposition is that the abdomen of Limulus be considerably elongated without other change. This would cause the imbrication of the members to cease—each appendage would stand out by itself although closely following each other. Then suppose that the sternal plate increase in size and unite with the ventral surface of the abdomen. Thus the gill-book cavity would be entirely filled up by the sternal plate except in those cavities on the ventral side which contain the gills or lungs, now greatly reduced in size. In this condition the lungs are quadrangular plates, attached by two edges only. Inserted on each plate is a number of lamellæ which are attached by one side only. In this condition when removed from the water, the lamellæ would cling together and be imperfectly in contact with the air. To be of service the lamellæ would have to unite their lateral edges to the plate, leaving only the posterior edge free. Thus MacLeod developed the lamellæ and other structures of the lungs of Arachnida. By a comparison of structures in the adult form, MacLeod came to the conclusion that the tracheæ of Spiders are developed from the lungs.

J. S. Kingsley ('85 and '93) advances a much simpler explanation to account for the transition from a Limulus gill-

book to the lung-book of a spider or scorpion. By a sinking in of the whole appendage bearing the gill-leaves and an increase of the inpushings of the integument and a decrease in the outgrowths, the whole matter is explained. This involves a diminution of growth on the anterior side of the appendage and an increase of growth on the posterior side. These conditions would carry the appendage within the body wall where it would be situated as seen in the adult—the spiracle at the posterior end of the lung cavity and the lamellæ projecting toward the posterior end of the body. As Kingsley states, viewed from a histological standpoint, the description of the pulmonary organ of the spider or scorpion applies, almost word for word, to the gill-book of Limulus. He believes that the lungs of spiders are the primitive and the tracheæ the derived structures. The tracheæ of the Hexapoda have no relation to the tracheæ of spiders, having an entirely different origin.

Malcolm Laurie ('90) in his article on "The Embryology of a Scorpion" thinks the lung-books are undoubtedly comparable to the abdominal appendages of Limulus but hesitates to decide which of two propositions he advances is the correct one. He inclines toward the view that the lung-books of Scorpions are invaginated, i. e. the edge of each lamella in the Limulus gill-book corresponds to the interior fold between the lamellæ in the Scorpion lung-book. He imagines that he sees difficulties in explaining his second proposition which states that the whole appendage has sunk without invagination into a cavity in the abdominal surface. By either proposition the air space of the primitive condition would be air space in the derived condition.

On the other hand many comparative anatomists, recognizing the homologies pointed out years ago by Lenckart, as existing between the lungs and tracheæ of spiders and believing that these last were the homologues of the structures known by the same name in the Hexapods, have failed to recognize the cogency of the reasoning of the advocates of the Arachnidan affinities of Limulus. Thus Arnold Lang in his Lehrbuch der vergleichenden Anatomie (II Heft, p. 548, 1890) writes that the respiratory organs of Arachnoidea are tracheæ—tubular and book-leaf tracheæ. His view of the morphological signification of the latter is that they are modified tracheal tufts which, standing close together, have been flattened into hollow plates. He believes that the view of those who would bring the gill-books of Limulus and the lung-books of scorpions and similar types into close relationship, is artificial and unsupported by comparative anatomy and ontogeny.

So, too, Bernard ('92) in "The Apodidæ" says it is easiest to believe that the lung-books of the various forms are only a

specially concentrated arrangement of tracheal tubes. He regards the tracheæ, including the lungs of all "Tracheates" as having their origin in dermal glands which have gradually been modified for respiratory purposes. He also states that in considering the relationships of these various forms, the limbs are of so little importance that one might almost be tempted to leave them out of account. In a later paper on "The Chernetidæ" Bernard ('93) repeats in substance his earlier views.

In a word, these authors, regarding the tracheal form of respiration as the primitive—a premise which the observations of Moseley on the tracheæ of Peripatus seemed to render valid—have looked upon the air tubes of the arachnids as the primitive and the lungs as the derivative condition.

The question thus brought into prominence can only be settled by tracing the development of the respiratory organs of the Arachnida. Several authors have touched upon this question. Thus Locy ('86) describes the later stages of *Agelena nævia* as follows: The lungs arise as a pair of extensive invaginations. In sagittal sections they appear as oblong plates of cells with the nuclei in parallel rows. These nuclei are flattened on one side and convex on the other. The cells of two adjoining rows unite by the edges toward which the convex sides of the nuclei project and thus a lamella is formed. Later the nuclei of adjoining cells fuse, forming protoplasmic pillars between which are the blood lacunæ. Around each lamella is a chitinous membrane—the ventral and the dorsal being continuous at the free (posterior) end of the lamella. The cells of the ventral wall become arranged into two distinct layers. A part of the development described takes place after the hatching of the egg.

A. T. Bruce ('86–'87) says that a lung-book of a spider may be regarded as an involuted appendage or appendages. He noticed that the abdominal appendages become less conspicuous and that slight folds appear on their *anterior* faces. He did not observe all the stages and, judging from his text and figures, it is very evident that he was confused in some of his interpretations. K. Kishinouye ('90) states that in the basal part of the first abdominal appendage there is an ectodermic invagination—not deep or large. The wall of this pocket which faces the distal end of the appendage is thicker and its cells become arranged in parallel rows. Two of these rows, adhering to each other, produce a lamella. He confirms Locy's description of the later stages. On the second abdominal appendage is another ectodermic invagination—a deeply invaginated tube which remains in about the same state of development until after hatching. The appendage shortens

but is not invaginated. He believes it is very probable that the lungs were derived from the respiratory apparatus of some Limulus-like, aquatic form. He thinks that tracheæ are modified lungs.

Laurie ('90), beginning with his stage K, describes the changes in the abdominal segments of the Scorpion. At this stage the pectinæ and lung-book appendages are about equal in size and structure. In stage L, the pectines have become folded in a direction transverse to their axes. The other appendages are pushed in, forming little cavities (directed forward) on the posterior sides of the appendages. In the stage M the pectines are separated from the body wall at their distal ends. The lung-book inpushings are deeper and the cavities are divided up by lamellæ. In the last stage described (just before hatching) the pectines and lung-books have much the same structure as in the adult.

Morin ('88)* states that the lungs of the dipneumonous spiders arise in form of infoldings at the bases of the two appendages of the second abdominal segment. At the anterior end of the sac on the dorsal side, is an infolding which is the beginning of the lung leaves. The space between two leaves connects directly with the body cavity. Two adjoining leaves unite by the fusing of cells, as described by Locy. He agrees with Locy as to the later stages. Morphologically the lungs of Arachnida show great resemblance to the gills of Limulus and similar forms. He emphasizes the position of the infoldings on the posterior side of the appendage in both cases. The lungs of Spiders are merely sunken gill-books of Limulus. As the appendage sinks the stigma is left as an opening between the posterior wall of the appendage and the body wall. This author agrees with those who believe that tracheæ are modified lungs.

It must not be forgotten that Elias Metschnikoff ('70) described some features of the lungs of the Scorpions but it is not easy to understand either his text or his figures beyond the fact that he states that the lungs develop behind the abdominal limbs.

As will be seen from the foregoing summary, the development of the respiratory organs of the Arachnids has not been followed throughout and the gaps in our knowledge are at just the most critical points. To supply these deficiencies the investigations described below were undertaken.

The work was done in the Biological Laboratory of Tufts College. The eggs used were those of *Agelena nævia* and *Theridium tepidariorum*. The eggs were killed in water

* As summarized by Korschelt and Heider, '92, pp. 604–607. I cannot refer to the original text.

heated to 80° C. and hardened in alcohol, beginning with 50 per cent. The staining was usually *in toto* with alum cochineal. The sections described, unless otherwise specified, are sagittal.

In the first stage studied, corresponding in general to Locy's fig. 6, somite VII is cut off from somite VIII. Somites VIII and IX are still united (fig. 1) and the unsegmented mesoderm extends farther back. The ectoderm is a single layer deep except a portion over somite VII (possibly the anlage of an appendage) and between VIII and IX. The infolding of ectoderm shows the first differentiation of external segmentation.

In the next stage (fig. 2) which is about midway between Locy's figures 6 and 7, the second abdominal somite is differentiated, and to a less extent the line between somite IX and somite X, which has developed, is marked off. The ectoderm has become thickened from somite VII to somite IX. It is to be noticed that the cœlomic pouches are flattened in all except somite VIII.

The succeeding stage (fig. 3) shows the same features carried still farther. The XI somite has appeared. This stage corresponds to Locy's figure 7 or a stage a little earlier. I may note here that I have found at least as many cœlomic pouches as are described by Kishinouye in his "Note on the Cœlomic Cavity of the Spider," 1894.

After the stage just mentioned the appendages begin to be formed; no detailed account need be given of the external appearance of these, as in the main, my observations are but the repetition of those of various authors, from Claparède to Kishinouye. They grow out, one on either side of somites VIII–X, as rounded knobs.

Pulmonary organs.

In figure 4, which represents somites VII and VIII, the early appearance of the appendage is seen. In somite VII the cœlome is already greatly reduced and no trace of an appendage is to be seen. In the next somite (VIII) the appendage is plainly visible. It is marked off from somite VII by a slight groove, while the groove separating it from somite IX is deeper and directed forward, giving the limb a markedly backward direction, a tendency which is even more pronounced in later stages. Its outer wall is formed of several layers of cells while the cœlomic pouch sends into the budding appendage an outgrowth like that described by various authors.

With farther growth the conditions just described become more strongly emphasized; the anterior demarkation of the appendage becomes more and more faint, while behind, the inpushing becomes more and more marked, so that eventually a pit is formed, actually extending into the general body sur-

face, the outer wall of the pit being formed by the appendage whose growth we are tracing. This pit forms the pulmonary sac and the opening of the inpushing persists as the respiratory stigma. At no time do the appendages rise to any considerable distance above the general abdominal surface.

The changes described can be seen by a glance at fig. 5 which, besides the points already mentioned, shows some other features worthy of notice. The cœlome of somite VII still persists. That of VIII has become divided into two portions, one of which remains in the appendage, while the other portion, reduced in size, has been pushed backwards by the ingrowing pulmonary sac. The sac itself is irregular in outline, its inner wall being slightly undulating, while its outer wall, i. e. the morphologically posterior surface of the appendage, has its ectoderm thrown into folds, the anlagen of the leaves of the lung-book. The ectoderm lining the inner wall of this sac is but a single cell in thickness, but that of the appendicular side is thicker, the nuclei being rather irregularly arranged, the pulmonary ingrowths forcing their way between them. In this stage but two lung leaves are outlined, as shown in the figure.

In eggs of the same lot as the last, a stage apparently a little older was found; and from it the section figured in 6 was drawn. In its general features the changes are slight but there are some details of importance. From the fact that the plane of this section is not the same as that of the last, the appendicular cœlome is not shown, while the cœlomic cavity of the body is here much larger. So, too, the inner wall of the pulmonary cavity is shown to be thicker, a fact probably due to the obliquity of the section. In this stage four gill leaves are shown, the most developed ones being the most distal ones. In these, too, the nuclei are already arranged with their major axes parallel to the plane of the leaves. Proximally the leaves are much shorter and the nuclei are irregularly arranged. These facts place it beyond a doubt that the growing point of the organ is at the base of the appendage, a point of no little importance in comparison with the Xiphosures.

Figure 10 shows the ventral view of the embryo at the stage which figures 5, 6 and 8 represent in sections. This stage is about two or three days before the reversion of the embryo. Changes during this period are very rapid. In 4–5 days after this stage the lungs are almost fully developed and have about the same appearance as in hatched specimens, except in size and number of lamellæ. The embryo hatches in from 7–8 days after the stage figured in 10.

With the reversion of the embryo, the changes rapidly proceed toward the adult condition. In fig. 7 I insert an illustra-

tion which serves to connect my account with the papers of Locy, Kishinouye, Laurie and others. Here the gill lamellæ have slightly increased in number while they have become greatly increased in length. In the figure the pulmonary sac is somewhat funnel-shaped owing to a pulling open of the spiracle in some process of manipulation.

From this stage the transition to the conditions described by MacLeod and Locy is but slight and although I have studied the later stages up to and even beyond hatching, my observations are but a confirmation of theirs and so I do not repeat them here. The lungs are well developed and apparently ready to function as respiratory organs at the time of hatching. With the growth of the young spider the principal changes are an increase in the number of lamellæ and a corresponding increase in the size of the pulmonary organ, the new lamellæ being formed at the inner end of the sac.

Tracheæ.

The study of these has been a matter of considerable difficulty and I have been able to follow with certainty only the earlier stages. The tracheæ arise behind the appendage on somite IX, which, in its earlier stages has exactly the same history as appendage VIII. There is the same inpushing behind the limb, which results in its taking a position not pointing outward but towards the median line and backward. In fig. 8 is seen the first differentiation of the tracheæ. The inpushing has given rise to the spiracle as before, but the sac which results does not show so markedly those infoldings of the appendicular wall which occur in the case of the lungs. There is at most but a slight undulation of this surface. At the inner end, however, two ingrowths are seen, the earliest indications of the formation of the tracheal twigs. It is, however, easy to see that these inpushings are to be compared with the infoldings which produce the lamellæ, while the undulations just referred to admit of the interpretation that they are aborted lung leaves.

After the reversion of the embryo the same parts can be recognized (fig. 9). The inpushing has been carried to a greater extent, and sections in other planes show that this ingrowth is tubular in character. The cells lining its walls are elongate and are already taking the character shown in the tracheæ of the adult. At the inner end of the tracheal trunk thus formed, the nuclei are arranged in a radiating or bush-like manner, apparently indicating that here is the place where the trunk is about to divide into the tracheal twigs, but I have not been able to trace any tracheal lumina between these cells. I have not followed the later history of the tracheal system with any

detail but think that the foregoing is sufficient to justify my thesis that the tracheæ and the lungs are to be regarded as homologous structures.

Conclusions.

From the preceding it will be seen that:

I. The lungs of the spider arise as infoldings upon the posterior surface of the appendages of the second abdominal somite in the same manner as described by Kingsley ('85 and '93) for the gills of Limulus. They have the same growing point at the base of the appendage and form the lung leaves in exactly the same way that the gill-leaves arise. In other words, the lung-book of the spider (and presumably of all arachnids which possess one) arises at first as an external structure upon the posterior surface of the abdominal appendages. These appendages sink in, without any inversion or other complications, in exactly the manner theoretically deemed probable by Kinsgley, so that there can no longer be any doubt as to the exact homology existing between the lungs of the spider and the first pair of gills in the horse shoe crab.

II. The tracheæ develop from the next pair (third abdominal somite) of limbs. In their earlier stages these appendages show on their posterior surface a folding similar to that on the preceding members. From this it follows that the lung-book condition is the primitive, the tracheæ of the Arachnids being derived from it. And with these facts there is left no ground for those who regard the "Tracheata" as a natural group of the animal kingdom.

Tufts College, Mass., May 25th, 1894.

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EXPLANATION OF THE FIGURES.

Reference Letters.

a^1.–a^{11}. Appendages.
c^1.–c^{11}. Cœlomic cavities.
e. Ectoderm.
m. Mesoderm.
pc. Pulmonary cavity.
pl. Pulmonary leaves.
s. Spiracle.
so. Somatoplure.
sp. Splanchnoplure.
t. Trachea.
y. Yolk.

All figures except fig. 10 are magnified 125 diameters.

EXPLANATION OF THE PLATE.

Fig. 1.—A sagittal section showing the cœlomic cavities of the VII, VIII and IX somites.

Fig. 2.—A sagittal section through the same region as the preceding at a little later stage. The coelomic pouch of the X somite is seen as well as the inpushings of ectoderm behind somites VII and VIII.

Fig. 3.—A section cut under conditions similar to those of the two preceding sections. The stage is a little later than fig. 2 and shows the cœlomic cavity of somite XI and further inpushings of the ectoderm. In all of the preceding sections the somatopluric wall is the thicker.

Fig. 4.—In this figure the cœlome of somite VII is much reduced in size. The cœlome of VIII is beginning to thrust itself into the appendage, which is marked off by a shallow groove in front and by a deeper inpushing, which has a forward direction, between somites VIII and IX.

Fig. 5.—In this section the inpushing, seen in fig. 4, has gone much farther, dividing the cœlome of somite VIII into two parts. On the inner wall of the appendage are two inpushings which are the beginnings of the lamellæ of the lung book.

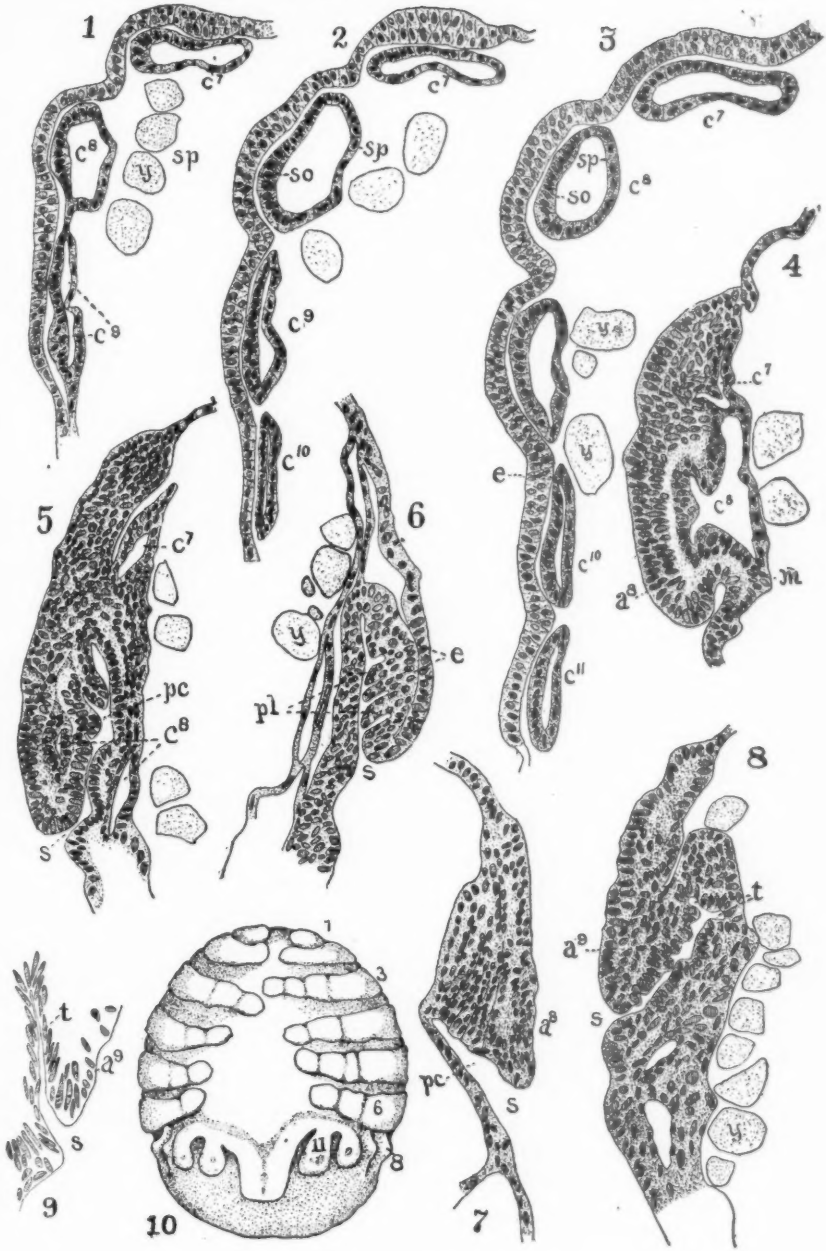
Fig. 6.—A section of the appendage of somite VIII cut at a different angle from the preceding. Here four lamellæ are seen.

Fig. 7.—A sagittal section from a stage just after the reversion of the embryo.

Fig. 8.—A section of the appendage of the IX somite, showing, at the inner end of the inpushing, the beginning of the tracheal tubes.

Fig. 9.—A section of the tracheal region after the reversion of the embryo.

Fig. 10.—This figure is a representation of the ventral surface of an embryo which is about the same age as those from which sections seen in figs. 5, 6 and 8 were cut.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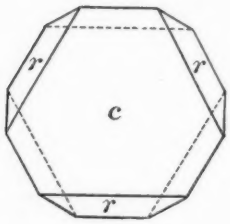
Art. XVI.—*On Alunite, from Red Mountain, Ouray County, Colorado;* by E. B. Hurlburt.

The alunite which will be described in this communication occurs as an aggregate of minute crystals, resembling kaolin, filling pockets and seams in the ore body of the National Belle Mine at Red Mountain. The ore that is mined is chiefly enargite with some tetrahedrite and pyrite. A small quantity of the mineral was observed by Prof. S. L. Penfield on some enargite specimens among material which had been collected by him while engaged in summer work with the United States Geological Survey, and through the kindness of Mr. W. B. Wilson, superintendent of the mine, an abundant supply was obtained. It was at first supposed to be a well crystallized kaolin, similar to that described by Hills,* Cross and Hillebrand† and Reusch‡ from the same mine, but the shape of the crystals and the optical properties did not correspond to the description of the above named authors. Moreover when heated in a closed tube abundant water was given off along with SO_3 and SO_2 and the mineral was determined to be alunite.

The form of the crystals as seen under the microscope is a combination of rhombohedron and base, shown in vertical projection by the figure. The largest crystals were about 0·13^{mm} in diameter and 0·01^{mm} thick. Professor Penfield succeeded in measuring one of these minute crystals on the reflecting goniometer but the faces were somewhat rounded so that they did not give good reflections, the angle of base on rhombohedron was found to be about 54° while Breithaupt gives for alunite $c \wedge r$, $0001 \wedge 10\bar{1}1 = 55° 20'$. The crystals exhibited normal optical properties and positive double refraction.



To secure suitable material for analysis the mineral was suspended in water and the smaller crystals poured off. The larger ones were then brought into the potassium mercuric iodide solution and further purified, that portion which was taken for analysis, and which constituted the bulk of the material, varied in specific gravity between 2·826 and 2·843,

* This Journal, III. xxvii, p. 472, 1884.
† Bull. Geolog. Survey 20, p. 98, 1885.
‡ Neus Jahrb., 1887, ii, p. 70.

which is considerably higher than that given by other authors for alunite.

The results of the analysis are as follows:

		Ratio.		Theory where K : Na : 4 : 7
SO_3	38·93	·486	4·00	39·65
Al_2O_3	39·03	·382	3·12	37·93
K_2O	4·26	·042	·117	4·21
Na_2O	4·41	·075	·95	4·83
H_2O	13·35	·741	6·07	13·38
Insol.	·50			
	100·48			100·00

The ratio of $SO_3 : Al_2O_3 : (K+Na)_2O : H_2O$ is very nearly 4 : 3 : 1 : 6 as required by the commonly accepted formula of alunite $KAl_3S_2O_{11}$, $3H_2O$. The agreement between the theory and analysis is satisfactory. The mineral suffers no loss by heating in an air bath at 300° C. and water is first given off at a temperature near redness. It is therefore to be regarded as water of constitution and the formula should be written $K[Al(OH)_2]_3(SO_4)_2$.

An interesting feature of this analysis is the large percentage of sodium, the ratio of K : Na being about 4 : 7, while alunite has usually been regarded as a potash compound only. Another interesting feature is the insolubility of the mineral in hydrochloric acid. By digesting for two weeks on the water bath 13·30 per cent of the mineral and 3·84 per cent of SO_3 went into solution.

The occurrence of alunite from the Rosita Hills in Colorado has been mentioned by Cross,* who regards its formation as the result of solfataric action on rhyolite. The material described by him consisted of immense rock masses made up essentially of alunite and quartz. He cites an analysis of nearly pure white crystals made by Eakins in which the ratio of K : Na was found to be nearly 4 : 7 corresponding to the material from Red Mountain. The origin of the mineral from this last locality is probably similar to that from the Rosita Hills.

In closing the author desires to express his thanks to Professor Penfield for valuable advice during the progress of this examination.

Laboratory of Mineralogy and Petrography,
Sheffield Scientific School, 1894.

* This Journal, III, xli, p. 466, 1891.

ART. XVII.—*On the Geographic and Hypsometric Distribution of North American Viviparidæ;** by R. ELLSWORTH CALL, Louisville, Ky. (With Map.)

IN some respects these unattractive mollusks constitute a remarkable assemblage of natural forms. They are not widely separated in point of geological history from the Mississippi valley *Unionidæ* which, with these shells, apparently date back to strata of Laramie age. Specimens referred to this genus have been described from Laramie rocks in Montana, Colorado, Wyoming and British America. It is more than probable that from this region as a center all the recent forms have been derived.

The *Viviparidæ* of North America are all comprised in four genera. Of these the species numbers, as well as individuals, differ widely. The recognized natural genera are *Tulotoma*, with two species; *Lioplax*, with two species; *Vivipara*, with four species; and *Campeloma*, with nine species. There are many synonymic names, chiefly in the Campelomoid section which is the most widely distributed and is by far the most abundant in individuals. Questions of priority in no wise enter into the plan of this paper which has to do solely with questions of geographic distribution and the hypsometric range of the several forms. Yet, to prevent misconception, it will be necessary to indicate the names which we believe, with present information, must be applied to the members of these groups. The remaining names, familiar to students of mollusca, will be regarded as synonyms of one or another form herein listed.

With this restriction, then, it is proposed to recognize in *Tulotoma* the following forms:

Tulotoma magnifica Conrad.
Tulotoma coosæensis Lea.

In *Vivipara* the following forms will stand:

Vivipara intertexta Say.
Vivipara subpurpurea Say.
Vivipara contectoides W. G. Binney.
Vivipara troostiana Lea.

The genus *Lioplax* will comprehend the following forms:

Lioplax cyclostomatiformis Lea.
Lioplax subcarinata Say.

* Read before the Indiana Academy of Sciences, December, 1893.

The largest genus, *Campeloma*, will have the following species and varieties:

Campeloma ponderosum Say.
Campeloma decisum Say.
Campeloma subsolidum Anthony.
Campeloma integrum DeKay.
Campeloma rufum Haldeman.
Campeloma coarctatum Lea.
Campeloma decisum geniculum Conrad.
Campeloma limum Anthony.
Campeloma integrum obesum Lewis.

The specific facts here indicated may not be in accordance with those which are usually held by collectors. But this arrangement is based upon the examination of several thousand specimens from all over the wide range of territory to which they belong. What disposition may be made of several problematical forms will depend upon more complete collections in the southwestern portions of the Union.

The species of *Campeloma* of widest geographic range is *Campeloma decisum* Say. Rather more than two thousand specimens of this form alone have passed in review during the past twenty years until its particular features render it very easy of identification. This form ranges from the Dartmouth Lakes, Nova Scotia, northwestward through portions of Quebec and Ontario to the northern shore of Lake Superior and on to the Saskatchawan river, British America. Throughout all this region it is commonly scarce, being found nowhere in abundance except in the St. Lawrence, near Montreal. From Nova Scotia southwards the species ranges throughout New England to Maryland and Virginia. It does not occur south of the Ohio river in the region west of the Appalachian system. That is to say no forms which may not better be referred to some other member of the group have yet occurred south of that stream. The westernmost range of the form is Michigan and Minnesota. Under the name of *Campeloma decisum* however numerous shells belonging to the related *Campeloma subsolidum* have been submitted to us and very many more are to be noted in the United States National Museum and in other large collections. But typical *decisum* has to be looked for only within the portions of the country above outlined. The variety herein designated as *Campeloma decisum geniculum* Conrad will extend the range far to the south but the characters of the variety appear to be so constant and to have such well defined geographic limits that it is deemed best to separately consider it.

Campeloma decisum is a very abundant shell in Central New York, in the Mohawk river and especially in the Erie Canal wherein are to be found the optimum conditions for development and growth. Indeed, as one passes from Maine westwards to New York the form appears to become increasingly abundant. It finds its maximum in individuals in New York and either ceases entirely in the regions about or gradually is replaced by the other forms mentioned herein.

Conrad's form, the geniculate variety, has been discovered in South Carolina and onwards to middle Alabama. It is a very common, often abundant shell in the larger streams of Georgia and in the smaller ones of the northern portions of that State and Alabama. Extensive collecting over all the regions in northwest Georgia never failed to reveal it in all streams in which mollusks of any sort were found, except, indeed, in the very smallest. In most of the tributaries of the Coosa it appeared and always with its well marked characters. Its range may be regarded as pretty well limited by a line drawn along the Appalachians from the boundary of North Carolina to near Wetumpka, Alabama, thence southeastwards to the Flint river at and below Albany. Thence it passes northwards to middle South Carolina and to the place of starting. Without this area it has not yet been detected. What relation, if any, this peculiar form may sustain to the conditions of its environment as a causal factor in determining its modification one may only guess rather than state. But it is believed that therein will lie the explanation.

The most widely distributed western species of *Campeloma* is the form described by Anthony as *C. subsolidum*. Under the various synonymic names of *C. milesii* Lea and *C. exilis* Anthony the typical shell occurs over a very extensive region, embracing Indiana, Illinois, Iowa, Michigan, Minnesota, Nebraska, Kansas, Missouri, and portions of Arkansas and possibly Kentucky. Specimens which are best referred to this species have been submitted from Arkansas but they pass into the more southern and characteristic *Campeloma coarctatum* Lea. Over southwestern Michigan and in Minnesota this shell is very abundant and quite characteristic. In the lakes of Northern Indiana and Illinois, as well as in those of Minnesota, the shells are lighter both in texture and in color than when found in rivers or creeks. To this circumstance is due the reference of very many specimens of this form, which is quite characteristic, to *Campeloma decisum*. Throughout the Upper Mississippi river this is the only species of *Campeloma*. North of St. Louis it gradually grows more common becoming abundant in that stream along Iowa and Illinois shores. The most northern localities are Ft. Snelling, Minnesota,

whence come specimens from the Minnesota river, and the Big Sioux river. To the south of Missouri it is replaced by its congener *Campeloma coarctatum* Lea. It has never occurred in any stream which is not tributary to the Mississippi or which does not belong to the Mississippi drainage. Its center of distribution appears to be the Mississippi river in that portion of its course which lies between Minneapolis and Keokuk.

Numerous examples of a much thinner and lighter colored variety come from ponds and lakes all over the area of distribution of this species. To these collectors commonly give the name of *Campeloma decisum* Say. But the less ventricose whorls, elongated peristome, dark olive color, longer spire and heavier texture will serve to differentiate them from Say's form.

The form described by DeKay as *Campeloma integrum* has a less wide distribution than either of the forms previously mentioned. Rare specimens have been found in western Connecticut and Massachusetts. In New York, particularly in the Erie Canal, it is very abundant and large. Thence it ranges westwards to middle Ohio where it assumes such widely diversified characters that a variety name has been established for it. In southern Michigan and western Indiana this species occurs in considerable abundance but nothing like those in which it is found in the New York localities. It has not been reported south of the Ohio river nor south of Pennsylvania. The specimens which have been reported from west of the Mississippi river belong either to Anthony's species or to the variety mentioned below. The limits of distribution of DeKay's form then will be from western New England to Indiana and Michigan and, so far as we now know, mostly in streams of the Lake drainage.

Campeloma integrum obesum Lewis, belongs only to the region west of the Appalachians and north of the Ohio river. It came originally from Columbus, Ohio, where it abounds. Specimens have been taken in considerable numbers in Kent county, Michigan. In the Rouge river, Grand river and Reed's Lake, in Michigan the species abounds. West of the Mississippi river it has occurred only in one locality, near Iowa City, Iowa, where it exists in very large numbers in a small stream. About Columbus, Ohio, the species appears to be very prolific. Dr. James Lewis, who described this shell, originally based his work on the male shell. Later the female form, with young shells in the ovisacs, fell into his hands; the great numbers of young coupled with the much more ventricose form of the body whorl caused him to erect a new species which he called *Campeloma fecunda*. The identity of the two is now estab-

lished beyond question. It may not be uninteresting, in this connection, to say that *Campeloma exilis* Anthony and *Campeloma milesii* Lea are both species which are based upon the male of *Campeloma subsolidum* Anthony; the males of all the known species are very much smaller, in every corresponding dimension, than are the females.

The form described as *Campeloma rufum* Haldeman has a fairly wide range over the northern United States from Taunton, Massachusetts, and Waterbury, Connecticut, to Rum river, in Minnesota. It is common and abundant in New York, Ohio, Michigan, Indiana, and in northeastern Illinois. It has been seen from west of the Mississippi river only in the State of Minnesota, from a locality near Anoka. From streams which flow into the Tennessee river in east Tennessee, notably in the Hiawassee river and Tellico creek, come specimens which are referred to this species. In all the large number of examples which have passed in review the characters are remarkably constant. The highly polished epidermis, pink apical whorls and usually ruddy interior distinguish it readily from its congeners. Examples of other forms, with this name frequently come to us; but they are often examples colored with iron oxide. The epidermis of very young examples is somewhat hirsute while striæ parallel to the sutures occur on all typical examples. The southernmost locality from which examples have come to us is Huntsville, Alabama.

A nearly related form comes from the southern States all the way from South Carolina to Florida and west to Alabama. This is the *Campeloma limum* Anthony. The northernmost locality is the Santee Canal and the southernmost Wekiva river, Florida. From Montevallo, Alabama, and Talledaga creek in the eastern portion of the same State come the westernmost representatives of this very beautiful shell. Its distribution is quite restricted and it may, perhaps prove to be but a highly marked aberrant form of *Campeloma rufum*. At present, however, the facts do not warrant their union.

The largest species of this genus is *Campeloma ponderosum* Say. Originally described from the Ohio it has now been recorded from nearly all its greater tributaries. It is not a form which occurs in small streams and has never been reported from lakes or ponds unless they were in connection with some great river, and in such relation as to receive the overflow. The form ranges from western New York, in streams tributary to the Ohio, to the Mississippi; southwards, along the west slope of the Alleghanies, it extends to the headwaters of the Coosa river, the Oostanaula and Etowah rivers. In the Alabama, which is but the continuation of the Coosa, and in the Tennessee rivers it is very common and very

large. At Bridgeport, in the latter stream are found gigantic specimens which are excelled only, in size, by specimens from the Cumberland at and about Nashville. In the greater tributaries of all these streams it occurs but, as in the region north of the Ohio, it does not exist in the smaller streams. West of the Mississippi the species has not yet occurred.

Over all the western States from Arkansas south to Texas and east to central Alabama ranges a form to which Mr. Lea gave the name of *Campeloma coarctatum*. In the White and Saline and St. Francis rivers in Arkansas as far as Caddo Lake and the Rio Brazos in Texas this shell is very abundant. Eastwards it occurs in numerous streams in Mississippi and south Alabama. The northernmost locality in the latter State is at Helena where it is exceedingly numerous in Buck creek. It appears to be most nearly related to *Campeloma subsolidum* being related to it somewhat as *Campeloma limum* is to *Campeloma rufum*. In northern Arkansas it is replaced by the typical western form, *Campeloma subsolidum* Anthony.

The genus *Lioplax* has but two representatives and these occupy not only entirely distinct areas but do not occupy the same drainage systems. The form of widest distribution is *Lioplax subcarinata* Say. The range of this species is from the Ohio river southwards to and including the Tennessee river; westwards to Missouri and central Iowa; northwards the range is limited to Minnesota in which State, at Ft. Snelling, in the Minnesota river, it occurs abundantly. In Illinois and Indiana it occurs somewhat numerously in certain of the larger streams. The only Kentucky habitat is the Licking river so far as present information goes. These localities are all west of the Appalachians. East of that system it has been reported only from New Jersey in which State it was originally found. With this exception it is limited to the north central States.

Its only other congener, *Lioplax cyclostomatiformis* Lea, is readily distinguished by its greater irregularity of outline, its rounded whorls and its characteristic orange colored aperture. It has occurred only in streams of the Gulf drainage. Under its proper name and the synonymic names of *Lioplax spillmanii* Lea and *Lioplax elliottii* Lea it ranges from east Mississippi in the Tombigbee river to Othcalooga creek in Georgia. In the Alabama, Cahaba, Coosa and Flint rivers it is very abundant. Its habit in the Cahaba and Coosa rivers, where we collected it in very large numbers, is very interesting and peculiar. It was found buried in the mud under large, flat rocks, from under a single one of which it was sometimes possible to take 300 or more examples! It occurred rarely in

the Black Warrior at Tuscaloosa. Unlike the northern shell many specimens were obtained in certain small creeks but always under conditions similar to those which obtained in the Cahaba.

Tulotoma magnifica Conrad will include all the forms described by Dr. Isaac Lea except the single one hereinafter mentioned. It is confined to a single stream in Alabama and has been obtained in but two or three localities in that river. From Wetumpka, Alabama, to a point just below Claiborne constitutes the extreme range of the genus and its two species. At Wetumpka it was found in wonderful abundance attached to the under surface of flat rocks in the most swiftly flowing portions of the river just above the government works. Its discovery was quite an accident and several days had been spent in its search when a fall revealed its whereabouts.

The second species of the genus *Tulotoma coosænsis* Lea is found only at Wetumpka and in similar situations. The very young and perfect shells are ornamented with minute hairs arranged in regular lines. The whorls are always much more convex than those of the associated form and the aperture is never angulated. All the other names are synonyms of these two; they chiefly apply to Conrad's form.

The widest distribution of the genus *Vivipara* is seen in the form *Vivipara contectoides* W. G. Binney. This occurs all over the Mississippi valley from Iowa to southern Missouri and eastwards to central Ohio. Southwards it extends to Mississippi, Alabama, Georgia and Florida, being abundant in all these States. East of the Appalachians its northernmost range is in South Carolina. But in central New York is a large area over which it has become distributed owing to certain favoring conditions. Dr. James Lewis colonized a number received from Illinois in the Erie Canal and from these have arisen a most wonderful number of descendants. The Erie Canal from Utica to Troy is alive with them; many have escaped into the Mohawk river and have there found a congenial home. Aside from this rapidly disseminating colony, however, no forms occur naturally east of the Appalachians in the northern States. In the southeastern States other forms have been based upon this species and these under the names of *Vivipara waltoni* Tryon and *Vivipara georgiana* Lea have been considered in stating the limits of this form. The southernmost locality west of the Mississippi river is Fourche Creek, Pulaski county, near Little Rock.

Vivipara intertexta Say does not occur outside of the Mississippi valley except in certain portions of Louisiana. It was originally described from near New Orleans whence it ranges northwards to White Bear Lake and Winona, Minnesota. In

eastern Iowa and portions of Illinois and western Indiana it is an abundant shell in ponds and bayous being rarely found in the more swiftly flowing rivers.

The most restricted species of the genus is *Vivipara troostiana* Lea described from Tennessee. The original locality was unknown to Lea who described it as having been received from Dr. Troost. I found it abundantly in a small stream at Murfreesboro and think it possible that this was the original locality. It has been found at no other place so far as we know and is still the rarest Viviparid in all our collections.

The form known as *Vivipara subpurpurea* Say is found over all the Mississippi valley from Caddo Lake, Texas, to Ft. Snelling, Minnesota; thence it ranges eastward into western Indiana. In the Mississippi river at Davenport and in the St. Francis river, at Wittsburg, Arkansas, it attains the maximum of numbers. It has somewhat the habit, at Davenport, of *Tulotoma* being very common under large flat rocks in the Moline rapids. In the more southern localities it is, like most of its congeners, a mud-loving form.

The facts connected with the hypsometric or vertical distribution of the *Viviparidæ* are relatively few in number and may be briefly recited. Of the localities from which we have seen specimens or of which we have any authentic record most of them lie between 100 and 700 feet altitude. The species which has greatest vertical range is *Campeloma decisum* which is reported from Hiram, Ohio, at an elevation 1260 feet. Many localities ranging from 500 to 800 feet altitude have been noted; but this one gives the greatest vertical range observed up to the present time. This genus has the greatest geographic range and it is not surprising that it should also furnish examples of extreme hypsometric distribution. From this altitude it extends downwards to sea-level or with 10 feet of it at Stonington, Ct., and several localities in New Jersey.

Campeloma subsolidum has the next highest distribution, specimens having been taken from the Des Moines river, Iowa, at Fort Dodge, at an elevation of 1100 feet. *Campeloma coarctatum* ranges to 890 feet, reported from Sedalia, Missouri. It ranges downwards to within 20 feet of sea-level as near the city of Natchez, Mississippi. *Campeloma rufum* has been reported from only one locality which reaches 1000 feet altitude, namely at Akron, Ohio. The same fact is true for *Campeloma ponderosum* which has its greatest vertical range at the same place. *Campeloma integer* has never been taken at an elevation greater than 735 feet, which locality is the St. Joseph river, at South Bend, Indiana. *Campeloma decisum geniculum* has been found at Athens, Georgia, at an elevation

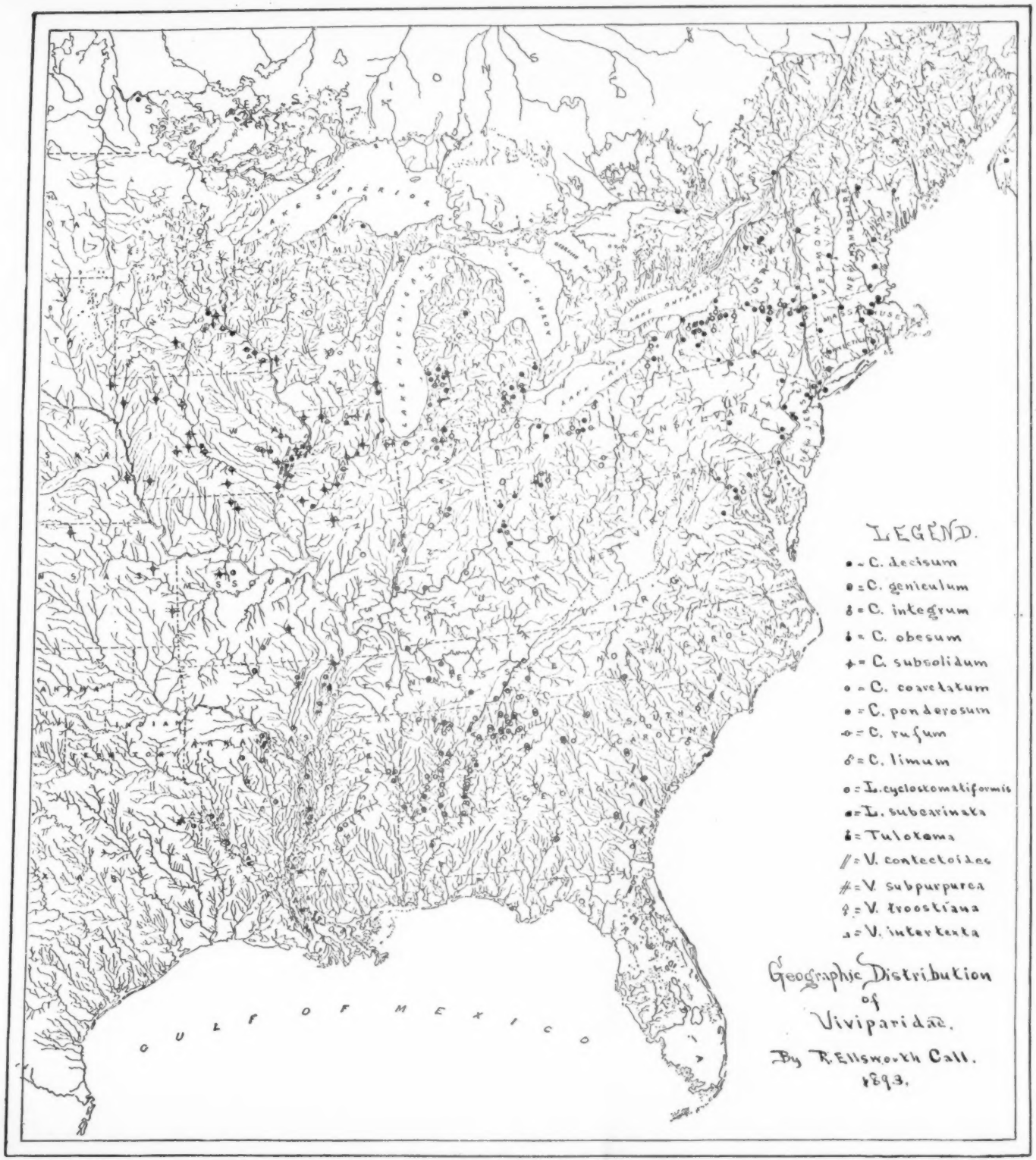
of 705 feet. Probably this form will be found to range considerably higher since we have many examples from streams in northern Georgia whose elevations are near that of Athens or even greater but there is no means of determining the exact height.

Summing up all the facts gleaned in comparing the elevations of the various localities from which the species of *Campeloma* have been sent to us the general statement may be ventured that the vertical range is constantly below 1300 feet. Furthermore, at the highest limit of range the species appear to be somewhat depauperate and in other ways show the influence of environmental factors of an unfavorable nature. The several species of *Campeloma* find expression in greatest numbers at from 150 feet to 600 feet elevation. Above that limit they are less numerous in individuals. This last range, then, may be safely regarded as the limit of range of optimum stations.

Of the genus *Tulotoma* little need be said. Occurring in only one stream, the Coosa river and its continuation the Alabama, the range of course is determined by its distribution in that stream. Claiborne, the southernmost limit, is about 16 feet elevation; Wetumpka, the northernmost range, is 185 feet elevation. Within these hypsometric limits, therefore, this genus and its two species are confined.

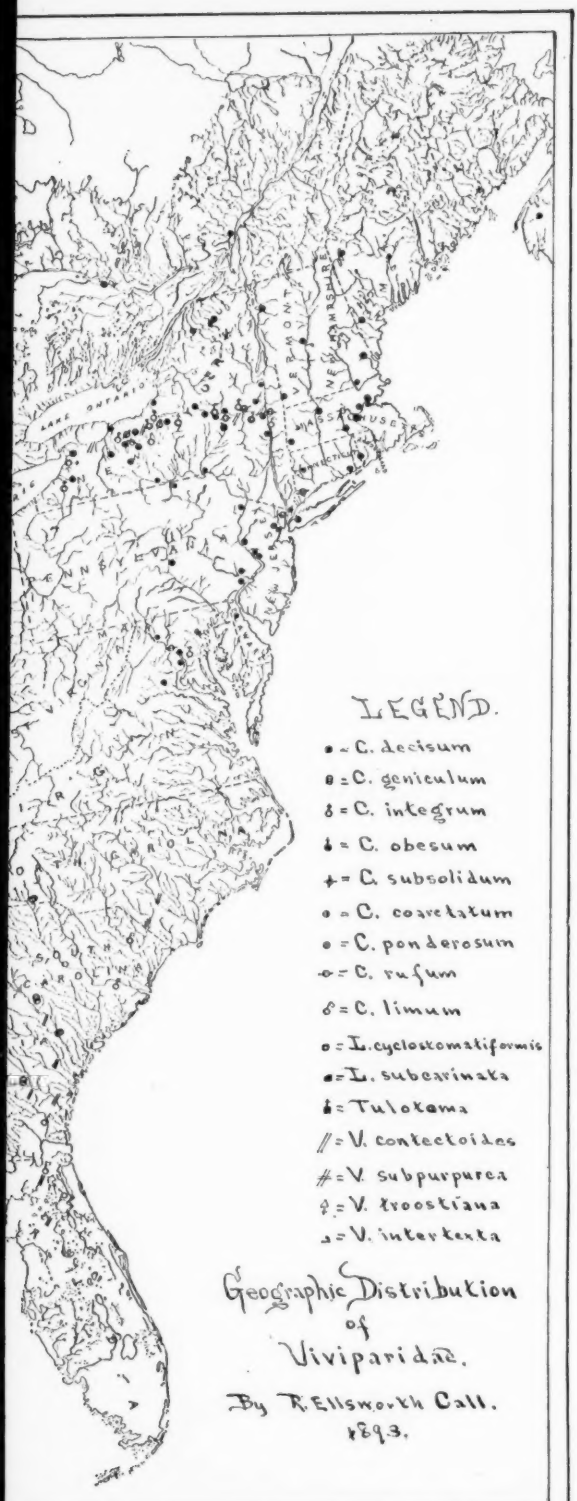
The genus *Vivipara* comes down to within 5 feet of the sea-level in Florida and Louisiana. From this point it ranges vertically to 1150 feet, in a sluggish stream near Eminence, Missouri, tributary to Jack's Fork, in the Ozark mountains, where it abounds. But one species, *Vivipara contectoides*, is found at this extreme elevation. Thence the range is down to 5 feet above sea-level near New Orleans, Louisiana. Like *Campeloma* the genus *Vivipara* has an optimum hypsometric range which falls between 50 and 500 feet. Of the 4 species which we have recognized *Vivipara contectoides* has the greatest vertical distribution. The form known as *Vivipara subpurpurea* comes next with a maximum vertical range of 722 feet, at which elevation it occurs in the Minnesota river, at Fort Snelling, Minnesota. It is practically impossible to make any comparisons between this shell and *Vivipara intertexta* which also has a similar range; the latter form, however, does not come so nearly down to sea-level.

The genus *Lioplax* has an extreme vertical distribution of about 722 feet which is the altitude of Fort Snelling, Minnesota, where it occurs abundantly. At the Jefferson Coal Mines, on the Warrior river, in Jefferson county, Alabama, abundant specimens of the genus, represented by *Lioplax cyclostomatiformis*, have been taken. The altitude of this



Geographic Distribution of Viviparidæ.

By R. Ellsworth Call. 1893.



Geographic Distribution of Viviparidæ.

By R. Ellsworth Call.
1893.

locality is 507 feet. Wetumpka, Alabama, at 185 feet, and Columbus, Mississippi, at 208 feet, represent the localities which are nearest sea-level. The form found here is the same as that of the Warrior river. The other form of *Lioplax*,—*L. subcarinata*—has a much greater range being found at Fort Snelling, in the Minnesota river, at an elevation of 722 feet, and in the Raritan river, New Jersey where it occurs in a station some 12 feet above tide water.

The accompanying map is designed to present at a glance the chief facts now known in the distribution of these forms. Its drainage features are based upon those of the United States Geological Survey Contour Map. In but a few cases have the mnemonics been employed on the face of the map. Their introduction in greater numbers would have obscured the facts sought to be illustrated in the distribution. Extreme localities for each form herein mentioned have been given and by an inspection of these and mentally connecting them the areas of individual distribution for the several species will be approximately shown.

Louisville, Ky., 18th Dec., 1893.

Art. XVIII.—*Mineralogical Notes;* by S. L. Penfield and D. A. Kreider.

1. *On the Identity of Hydrofranklinite and Chalcophanite.*

The name hydrofranklinite was given by W. T. Rœpper* to a supposed new hydrous oxide of iron, zinc and manganese, from Sterling Hill, near Ogdensburg, N. J. The mineral is described as crystallizing in small, brilliant, iron black octahedrons, with octahedral cleavage. The original chemical examination was never completed, and it seemed therefore desirable to investigate the mineral, an excellent suite of specimens in the Brush collection, which had been collected by Professor Brush at the locality in 1875, being available. The mineral occurs as a coating of minute crystals, the largest not over 1^{mm} in greatest diameter, deposited upon a manganese ore, which is possibly of the same composition as the crystals but not distinctly crystallized. As it was found to be practically impossible to separate the pure crystals by hand picking, the method suggested by Retgers,† of separating minerals of high specific gravity by means of fused thallium-silver nitrate, was resorted to, but a satisfactory separation could not be effected by this means as much of the gangue was of about the same

*Appendix III, 5th ed. Dana's Min., p. 61. Dana's Min., 6th ed., p. 259.
†Jahrb. f. Min., 1893, I, p. 90.

specific gravity as the crystals. It was noticed, however, in washing the pulverized mineral, that the crystals had a decided tendency to float, owing probably to the smooth surfaces that they possess, combined with the fact that water does not seem to wet them. By covering the powdered mineral with a shallow layer of water in a large beaker, and inclining the latter so that a wave or ripple passes over the powder, the crystals are readily brought to the surface, and by a little manipulation almost a continuous layer of them can be made to float on the water. By repeating this operation a number of times, and making fractional separations, a product was finally obtained which, when examined with a lens, showed only brilliant crystalline particles, and which could readily be made to float wholly upon a limited surface of water. The mineral was then further separated by means of the thallium-silver nitrate fusion and, excluding the heavier and lighter portions, a product of intermediate specific gravity was reserved for the chemical analysis. The specific gravity of this material, taken with the pycnometer, was found to be 4·012. Rœpper gives 4·06–4·09 and Moore 3·907 for chalcophanite.

The mineral when finely pulverized yielded a powder of a dark chocolate-brown color. A qualitative analysis showed the presence of iron, zinc, manganese and water. In the closed tube water is given off at a very low temperature, and on stronger ignition oxygen gas is liberated. The mineral is readily soluble in hydrochloric acid with evolution of chlorine. The results of the analysis are as follows:

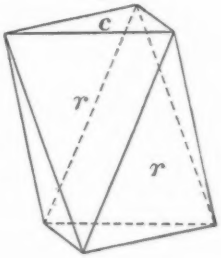
		Ratio.			Theory where Fe : Zn = 8 : 13
FeO	10·00	·139	·364	1·07	9·53
ZnO	18·25	·225			17·52
MnO	48·27	·680		2·00	49·33
O	11·21	·701		2·06	11·11
H_2O	11·85	·658		1·94	12·51
Insoluble	·25				
	99·83				100·00

The ratio of $(Fe+Zn)O : MnO : O : H_2O$ equals nearly 1 : 2 : 2 : 2, indicating that the composition of the mineral can be expressed by the formula $RO, 2MnO_2, 2H_2O$, or $RMn_2O_5, 2H_2O$, where R = Fe and Zn in the proportion of about 8 : 13. The above formula is identical with that derived by Moore* for chalcophanite, except that in the material analyzed by him iron was practically wanting and R = Zn and Mn. The agreement between our analysis and the theory is quite satisfactory. The water is a little low, but the material may have suffered a slight alteration as it loses its water very readily, some going

* Amer. Chemist, vi, p. 1, 1875.

off at 100° C. and nearly all of it by heating the fine powder for two hours at 200° C. The water is therefore water of crystallization and the mineral is undoubtedly to be regarded as a hydrated salt of the acid $H_2Mn_2O_5$. The acid in question is analogous to di-silicic acid, $H_2Si_2O_5$, a normal salt of which is represented by petatite, $LiAl(SiO_3)_2$. From a more careful examination of the crystals of the mineral it has been found that they are not isometric as stated by Rœpper, but exhibit a combination of rhombohedron and base as shown in figure 1, and yield a perfect basal cleavage. In reality the crystals look much more like octahedrons than would be inferred from the figure, since the faces are vicinal and the rhombohedral planes curve and flatten somewhat as they approach the base. No satisfactory measurements could be made, the angle $c \wedge r$, $0001 \wedge 10\bar{1}1$, varying several degrees, but averaging near that given by Moore for chalcophanite. The crystals described by him were scales and rarely plates, showing the combination of c and r.

Fig. 1.



We take pleasure in expressing to Prof. B. W. Frazier of South Bethlehem, Pa., our thanks for the loan of a specimen from the collection of Lehigh University which was labeled hydrofranklinite in Professor Rœpper's own handwriting and which was in every respect similar to the material analyzed by us.

2. *On the Separation of Minerals of High Specific Gravity by means of the fused Double Nitrate of Silver and Thallium.*

Mineralogists and petrographers are certainly indebted to Dr. J. W. Retgers for the fortunate discovery* that the nitrates of silver and thallium, when brought together in the molecular proportion of 1 : 1, yield a double salt, which fuses at 75° C. to a clear, mobile liquid, having a specific gravity of about 5 and miscible with water in all proportions at temperatures between its melting point and 100° C. The melting point also diminishes rapidly as water is added, going down to 50° or 60° C., and fusion and solubility pass uninterruptedly into one another. We have thus at our command for the separation of mineral particles a liquid far exceeding in specific gravity any of the previously described heavy solutions, and which has the advantage of being practically colorless, neutral, soluble in water and of being readily recovered from the aqueous solution by simple evaporation on the water bath. As suggested by Retgers, separations may be made in test tubes heated in a

* Loc. cit.

water bath. After a separation is completed and the fusion cooled, the test tube is broken and the solid cake divided, when the heavier and lighter portions may be obtained by dissolving the double salt. There are some disadvantages, however, in working with test tubes, especially as it is always convenient and frequently quite necessary to secure fractional separations or to draw off the heavy material from the bottom for examination, and with a test tube this cannot be accomplished without interrupting the whole experiment and clearing the material. As the ordinary glass stop-cock separating funnels are not well adapted for use with a fused salt at a temperature of near 100° C. an apparatus has been devised, which is illustrated by fig. 2 in one-fourth its natural size. The glass rod is ground into the tube with fine emery and serves as a stop cock. This apparatus slips inside of a test tube, and a rubber band is so adjusted around the top of it that the lower end of the tube comes to within a few millimeters of the bottom of the test tube. The tubes are most conveniently heated in a beaker of hot water and can be held in a vertical position by a simple rack or test-tube stand made of metal. The contents of the tube are conveniently agitated by means of a plunger made from a glass rod bent at one end as in fig. 3. Before drawing off the heavy material from the bottom it is best to place a loosely fitting perforated cork in the end of the separating tube, through which the rod passes and is supported so that the rod can be raised straight up and dropped back into place without fear of breaking the tube. Difficulty sometimes arises at this point from particles getting caught in the stopper, so that after the heavy portion has been drawn off the rod will no longer close the tube. If the particles are small and not too hard they may be ground out by twisting the rod, or if this cannot be done the fusion must be allowed to run out and the apparatus cleaned. But even in this latter case, there is a decided advantage in saving of time over the use of a test tube, as a separation has been accomplished, and the mineral powder and apparatus can soon be made ready for another treatment with a fresh portion of the fused salt. The stop-cocks need to be carefully ground in order to make them perfectly tight, as they are subjected to a considerable pressure from the column of heavy liquid, but a slight leakage is not especially objectionable as the few drops that leak out are caught in the outer test tube.

Fig. 2.

Fig. 3.

Laboratory of Mineralogy and Petrography,
Sheffield Scientific School, New Haven, April, 1894.

Art. XIX.—*Carboniferous Fossils in the Norfolk County Basin;* by J. B. Woodworth.

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In 1880, Messrs. Crosby and Barton published in this Journal* an account of the discovery by them of traces of fossil plants in the rocks of the Norfolk County basin in Massachusetts at a place near the present station of Pondville on the Walpole & Wrentham R. R. It was the opinion of the authors that these plants, together with the physical connection of the rocks of this basin with those about Attleborough, Mass., in the northern part of the Narragansett basin, were evidence of the Carboniferous age of the series of strata studied by them.

Subsequently, the vegetable nature of the fossils was called in question in an unpublished statement by an observer who had visited the locality and had examined the hollow casts described by the original discoverers. In April, 1892, the present writer under the guidance of Mr. Barton, to whom belongs the credit of the discovery, visited the locality, and from a small opening similar to the numerous larger holes which were appealed to in 1880 as evidence of fossil plants, abstracted the solid cast of a longitudinally, coarsely striated stem, probably but not certainly identifiable with a species of sigillaria or calamites. Between the cast of the interior and the matrix of sandstone was a limonitic and cellular layer apparently representing the cortical part of the plant, too poorly preserved for identification. In many of the holes originally described by Messrs. Crosby and Barton, the same ferruginous and cellular layer was seen. These plant remains occur in sandy beds or partings in a simple, quartzose conglomerate, which outcrops in nearly vertical strata along two lines on either side of a synclinal axis.

In greenish slates, lying above the conglomerate bed, were found cylindrical, vermiform casts, of small size, apparently the underground rootlets of plants. In none of these specimens, however, are afforded characters which enable one to discriminate them from plant remains which occur elsewhere in rocks of Devonian age,† the period to which the red beds of this basin were referred by Prof. Edward Hitchcock.

* Extension of the Carboniferous formation in Massachusetts, 3d ser., vol. xx, pp. 416–420.

† See Sir William Dawson, *The Geological History of Plants.*

In the summer of 1892, in the course of a rapid reconnaissance made in the Norfolk County basin, the writer found a second locality of fossils in the railroad cut about one-half mile north of Canton Junction station on the Old Colony R. R., and 15 miles south of Boston, a brief announcement of which was made in the 14th Annual Report of the Director. This section was examined by Mr. W. W. Dodge as early as 1875, and probable fossils were seen by him which he described, in *Notes on the Geology of Eastern Massachusetts*,"* as "dark, cylindrical forms which appear to be branching stems of some kind." I am indebted to Mr. Dodge for the privilege of seeing the specimens in his collection. They are unidentifiable stem-like bodies. Under the microscope in thin section, the dark ring which forms the cross-section of the body proves to be chlorite enclosing an axis of the same constitution as the matrix. The chlorite is evidently a metamorphic product. A similar chloritic coating is found on the impressions of calamites from this locality. Since the evidence from this locality confirms the conclusion reached by the geologists before mentioned as to the Carboniferous age of, at least, a portion of the rocks in this basin, the following account of the Canton Junction section is here given. For a more extended statement of the relation of these beds to those of the Narragansett Basin, the reader is referred to a forthcoming report on the Carboniferous rocks of this district by Prof. N. S. Shaler.

Granitite.—The cut just north of the station at Canton Junction is in the hornblendic granitite which forms the floor of the Carboniferous along the southern border of the Norfolk County basin. Two narrow dikes of diabase cut the granitite, with their contacts following nearly vertical sets of joints.

Carboniferous, gray series.—About 2500 feet north of the granitite exposure is a small outcrop of greenish and grayish slates, originally fine muds with interlaminated sandy layers. The strike is about N. 60° E., and the dip 65° to 70° south; the cleavage dips north about 70°.

The fine, shaly partings between the sandy layers carry flattened plant stems, adhering to the under surface of the bedding. Compressed stems of *Calamites* occur about one inch wide and finely striated. They are ill preserved, but one form suggests *C. cistii* Brgt., which, according to Lesquereux, occurs in the Narragansett basin. *Sigillaria* is also found in the same bed.

Northward, about 135 feet of beds are covered with drift, when there appears the following section, also fossiliferous:

* Proc. Boston Soc. Nat. Hist., vol. xvii, 1875, p. 414.

1.	Sandstone	12 feet.
2.	Shale (slaty)	10 "
3.	Sandstone	6 "
4.	Quartzose conglomerate	18 "
5.	Sandstone	10 "
6.	Shales (slaty)	6 "
7.	Sandstone	20 "
8.	Shales (slaty)	2 "
9.	Sandstone and shale (slaty)	75 "

The measurements are based on pacing, but are sufficiently accurate to exhibit the stratigraphic characters of the section, the dip and strike of which agree closely with that of the first outcrop. Flattened plant stems occur in the shales of bed No. 6 and again in No. 9. The plants are calamites and the stems of ferns, but no fronds of the latter have been found.

Carboniferous, red series.—For about 3800 feet north of the above described section, there are no outcrops along the line of the railroad. At this distance from the gray rocks, is a cut in reddish strata having the typical lithological characters of most of the rocks in the Norfolk County basin and the lower portion of the Carboniferous in Attleborough, Mass. The strata dip steeply to the south or are in places nearly vertical. The section from south to north apparently in descending order is as follows:

1.	Fine quartzite conglomerate, with quartz veins	25 feet.
2.	Red sandstone and slate	15 "
3.	Fine quartzite conglomerate, with quartz veins	20 "
4.	Red and gray sandstone	30 "
5.	Red sandstone	50 "
6.	Fine quartzite conglomerate and sandstone	10 "
7.	Red slate	6 "
8.	Limestone, a lens, highly cleaved	(1·5) "
9.	Red sandstone and slate	10 "
10.	Red slate	15 "
11.	Dike, diabase?	(1·5) "
12.	Calcareous white and red slates	2 "
13.	Red slates	10 "
14.	Calcareous slates	4 "
15.	Red slates	30 "
16.	Red sandstone, with veins of quartz and calcite	5 "
17.	Red slates	20 "
18.	Covered beds	100 "
19.	Red slates	50 "

These measurements, like those in the preceding sections are based on pacing, the succession being made out on the west

side of the railway track. This section was also measured by Mr. Dodge,* who evidently mistook the dip of the cleavage for that of the stratification planes, in making the beds dip 45° N. No fossils have been found in this section, and, except certain small pitted impressions and fine straight furrows seen in demi-relief on the underside of some red beds, no markings were seen on their surfaces. The calcareous portion of the section differs from the calcareous red shales of the Cambrian in Attleborough and Wrentham in the apparent absence of fossils, a characteristic of the limestone bands in the Carboniferous at Attleborough. In part, the carbonate of lime is of vein origin like the lenticular quartz bodies which occur in the same section.

It has been assumed that these red rocks in the eastern portion of the Norfolk County basin are of Carboniferous date. The same presumption has proved only partially true in the southwestern part of the basin between Wrentham and Attleboro, where a section of red calcareous and sandy strata of lower Cambrian age occupies a narrow belt in the midst of the red Carboniferous.† For this reason, and owing to the absence of fossils in what appears to be the lower portion of the section at Canton Junction, it seems unwise at the present stage of our knowledge to hold on mere lithological evidence all of the red beds in this field to be of Carboniferous age.

Northward of the last outcrop about half a mile, gray rocks recur on the east of the railroad with nearly vertical dip.

In addition to the occurrences above mentioned, fossils were also found in the glacial drift at the following localities:

1. In Canton, about one and a half miles south of the border of the basin: *Calamites cistii* (?) in a sandstone pebble.

2. In East Walpole, on the south side of Traphole brook, near the western end of the Neponset swamp, small bowlders carry calamites and plant stems.

In both these instances, the drift of the fossiliferous pebbles was from the north and from a distance not exceeding three miles, the limit of known Carboniferous in that direction.

The occurrence of, at least, three dikes in the Canton junction section is interesting as setting aside the sharp distinction which has been thought to exist between the Norfolk County basin and that of Boston north of the Blue Hills. The scarcity of exposures in the former basin is one of the reasons for the apparent difference in this regard.

Cambridge, Mass., May 28th, 1894.

* Op. cit., p. 413

† N. S. Shaler: On the Geology of the Cambrian district of Bristol County, Mass. Bull. Mus. Comp. Zool., xvi, 1888, pp. 13-41.

Art. XX.—*On the Determination of Ferrous Iron in Silicates;* by J. H. Pratt.

The determination of ferrous iron in silicates made by dissolving them in a mixture of hydrofluoric and sulphuric acids and titrating with potassium permanganate is one of the well recognized methods of analytical chemistry. The apparatus described by Prof. J. P. Cooke,* by means of which the solution can be made in an atmosphere of steam and carbon dioxide, is well adapted for preventing any oxidation by the air but the necessary appliances are not always at hand. Prof. S. L. Penfield has suggested to the author a simpler means for accomplishing the same purpose, namely to displace the air by carbon dioxide led directly into the crucible by means of a platinum tube, and at his request a series of experiments has been made to determine the accuracy of the method.

The arrangement of the apparatus is similar to that devised by H. Rose† for igniting precipitates in hydrogen. The solution can be accomplished by boiling in a crucible directly over a small flame and after cooling the contents are transferred to a beaker or caserole and titrated. With a 50^{cc} crucible one-third full, the boiling may be continued for ten minutes with safety, but if too much of the water and hydrofluoric acid are evaporated the resulting hot concentrated sulphuric acid will act as an oxidizing agent. The solution may also be made on a water bath, but experiments with black tourmaline which is a very difficult mineral to dissolve, have shown that nearly as much was dissolved by boiling for ten minutes over a flame as by heating quietly for two hours on the water bath.

For testing the method, weighed quantities of ferrous sulphate were used. In the first series of experiments dilute sulphuric acid was taken as a solvent, and the results indicate that the heating may be continued for a considerable time without fear of oxidation.

Time.	Method of heating.	FeO taken.	FeO found.	Error.
30 minutes	water bath	·0786	·0782	·0004—
3½ hours	water bath	·0711	·0709	·0002—
30 minutes	water bath	·0785	·0785	·0000
1 hour	water bath	·0978	·0979	·0001+
15 minutes	water bath	·1012	·1014	·0002+
10 minutes	flame	·0810	·0808	·0002—
10 minutes	flame	·0835	·0836	·0001+

* This Journal, II, xliv, 347.

† Handbuch der Anal. Chem., 1871, p. 77. Also Fresenius' Quantitative Analysis, American edition by O. D. Allen, p. 251.

In the second series, a mixture of hydrofluoric and sulphuric acids was taken, such as would be used in dissolving silicates. The results indicate that when hydrofluoric acid is present and the heating long continued, there is a slight oxidation. It is evident, however, from the results of the last five experiments that very accurate determinations of ferrous iron can be made by this method.

Time.	Method of heating.	FeO taken.	FeO found.	Error.
4 hours	water bath	·1214	·1202	·0012—
3 hours	water bath	·1054	·1047	·0007—
1 hour	water bath	·0866	·0862	·0004—
3 hours	water bath	·0459	·0458	·0001—
7 minutes	flame	·1527	·1525	·0002—
10 minutes	flame	·0445	·0445	·0000
8 minutes	flame	·0345	·0345	·0000
8 minutes	flame	·0421	·0424	·0003+
8 minutes	flame	·0472	·0479	·0007+

Fairly accurate determinations may also be made without the use of carbon dioxide, the contents of the crucible being cooled as quickly as possible after boiling, and titrated as usual. This is the method commonly employed for determining ferrous iron in silicates. To test the extent of the oxidation the following series of experiments was made, using a mixture of hydrofluoric and sulphuric acids as a solvent.

Time.	Method of heating.	FeO taken.	FeO found.	Error.
10 minutes	flame	·0843	·0825	·0018—
10 minutes	flame	·0594	·0578	·0016—
10 minutes	flame	·0739	·0728	·0011—

It is evident from these results that the errors are somewhat greater than in the cases where CO_2 was used.

In experiments with very refractory minerals, where only a portion is dissolved by the acids, the insoluble mineral can be filtered off after titration, and the filtrate evaporated in a platinum dish until all the hydrofluoric acid is expelled. After dissolving the residual sulphates, the iron is reduced by hydrogen sulphide, the excess of the latter removed by boiling and the total iron determined by titration. By these two determinations, the ratio of the ferrous to ferric iron is established, and as the total iron can be determined in a separate portion fused with sodium carbonate, the percentages of ferrous and ferric iron can be readily calculated.

In making these experiments it has been found best to use water that has been previously boiled to expel air and subsequently cooled. As an additional precaution the carbon dioxide was generated from cleavage pieces of calcite which

were freed as far as possible from air by boiling in water for some time and transferring them while still wet to the generator. The gas was washed with a dilute solution of sodium carbonate. With very refractory minerals the strongest hydrofluoric acid that is available, mixed with about one-fifth its volume of concentrated sulphuric acid, should be used, in most cases, however, dilute acids are sufficient and much more convenient. Occasionally there is a tendency for the mineral to settle on the bottom of the crucible and cause bumping, but this can usually be prevented by addition of some coils of platinum wire.

In conclusion, the author takes pleasure in expressing to Professor Penfield his thanks for valuable advice and assistance.

Laboratory of Mineralogy and Petrography,
Sheffield Scientific School, New Haven, April, 1894.

Art. XXI.—*The Action of Reducing Agents on Iodic Acid;* by Charlotte F. Roberts

[Contributions from the Kent Chemical Laboratory of Yale College—XXXI.]

I. *The Absorption of Nitric Oxide by Iodic Acid.*

The following investigations were first undertaken with the object of studying the solubility of nitric oxide in iodic acid. Although most chemical authorities agree in the statement that nitric oxide is absorbed by iodic acid with the separation of iodine, there is a certain indefiniteness with regard to the *degree* of solubility, which led me to investigate the subject for myself. Thus, Gmelin-Kraut states that "All the lower oxides of nitrogen decompose iodic acid into iodine and nitric acid, but the decomposition takes place only in presence of a considerable quantity of water," but the *degree of ease* with which the decomposition takes place meets with no comment, and the "considerable quantity of water" seems a somewhat indefinite condition. Kämmerer,* who is the authority referred to for the above facts, and who, some years ago, made a thorough study of iodic acid, says, without referring to any illustrative experiments, "At ordinary temperature, I_2O_5 is reduced only in aqueous solution by nitric oxide, but this gas is without action upon the water-free acid and its solution in concentrated sulphuric acid. At 100° the latter is very slowly, the water-free acid not at all decomposed."

A portion of this latter statement was very easily verified. Some nitric oxide was passed through the dry acid, and other

* Jour. für prak. Chem., lxxxiii, 73.

portions were collected and allowed to stand over sulphuric acid solutions of HIO_3 and I_2O_5, without any appreciable separation of iodine.

In order to test the solubility of the gas in *aqueous* solutions of iodic acid, the nitric oxide was prepared in a generator containing potassium nitrate and ferrous sulphate, the air having been previously driven from the apparatus by means of carbon dioxide. The gas was next passed into a Will and Varrentrapp tube containing potassium iodide, and then into a Geissler bulb containing the iodic acid. The experiment was made several times with iodic acid of various degrees of concentration, and always with the same result. There was no evidence of iodine being set free from the iodic acid, though the liquid showed occasionally a barely perceptible tinge of yellow. There was, however, a smaller amount of nitric oxide collected, by two or three cubic centimeters than should have resulted from the amount of nitrate used, and on two or three occasions, an odor like that of chlorine was observed about the Geissler bulb, when the apparatus was disconnected, which could only be explained on the supposition that gaseous hydrochloric acid was carried over from the generator through the potassium iodide.

A later experiment in which nitric oxide was collected in a tube containing iodic acid and hydrochloric acid so dilute that no reaction took place between the two acids in the cold, showed that under these circumstances the nitric oxide was absorbed without any separation of iodine and that the liquid became yellow and gave odor like that of chlorine, so that the above seemed a plausible explanation of the disappearance of some nitric oxide in the Geissler bulb without a simultaneous liberation of iodine.

Two or three experiments were then made with the apparatus as before but with the addition of a new absorption tube containing silver nitrate to prevent the hydrochloric acid from going over into the iodic acid. Still there was no evidence of iodine being set free. It seemed apparent then, that the nitric oxide was not sufficiently soluble in iodic acid so that it could be absorbed by simply passing it rapidly through the solution.

To determine whether the gas was soluble upon long contact with the iodic acid or not, different portions were collected in U tubes closed at one end and filled with solutions of iodic acid of different degrees of concentration. The gas had been collected and allowed to stand over potassium iodide and sodium hydroxide for from twenty-four to forty-eight hours before being transferred to the U tube, in order to remove completely any other oxide of nitrogen which might be present. Solutions of iodic acid were used in the different U

tubes varying from a saturated solution containing about 50 grams to 25 cubic centimeters to a rather dilute solution containing not more than 5 grams to 25 cubic centimeters. There was no apparent absorption as the gas passed up through the liquid, but after the nitric oxide had been standing over the iodic acid for a few moments, iodine appeared on the surface of the liquid. This deposit gradually increased in amount and the liquid rose in the tube, reaching its maximum in 24 hours or less, depending on the amount of gas used.

The result of my experiments, then, has been to show that nitric oxide is absorbed by solutions of iodic acid of any degree of strength, but the reaction takes place slowly even when the gas is confined over the acid, and not at all when passed rapidly through the solution.

II. *The Action of Reducing Agents on Iodic Acid in presence of Hydrochloric Acid.*

It has already been stated that when the nitric oxide was collected over iodic acid mixed with dilute hydrochloric acid, the gas was absorbed, but there was no liberation of iodine, and in some cases an odor like that of chlorine was observed when the tube was opened. A similar phenomenon was noticed with several other reducing agents. It is well known that iodic acid with *strong* hydrochloric acid, or *heated* with dilute hydrochloric acid, forms iodine chloride and may set free chlorine, but in these experiments the dilute acids were used in the cold, and there was no change apparent until the reducing agent was added. Besides the nitric oxide, other substances which had a similar effect were potassium iodide, sodium thiosulphate, arsenious oxide, ferrous sulphate, stannous chloride, and potassium sulphocyanide. If the reducing agent was added in a very concentrated form, iodine was sometimes evolved, and in many cases traces of iodine would first form where the reagent touched the liquid, but would disappear on shaking, and a light yellow liquid would result with an odor like that of chlorine.

The first explanation of this phenomenon that suggested itself was that the iodic acid was not immediately completely deoxidized by the reducing agent but was first transformed to a lower oxide of iodine* which was more active and therefore more easily acted upon by hydrochloric acid than the iodic acid itself, and that the chlorine thus set free united wholly or partially with the iodine formed by the first reduction. It was with the object of studying the reduction of iodic acid in the presence of hydrochloric acid that some experiments were

*Gmelin-Kraut, Anorganische Chemie, I, 2, 290–292.

undertaken with potassium iodide, iodic acid, and dilute hydrochloric acid. Potassium iodide was chosen as the reducing agent on account of the simplicity of its oxidation products. Approximately $\frac{N}{10}$ solutions of iodic acid and potassium iodide were used and dilute hydrochloric acid of specific gravity 1·05. The latter acid was so dilute that it could be added in apparently indefinite quantities to the iodic acid without producing any perceptible odor or change of color.

With 10^{cc} of iodic acid and half that volume of hydrochloric acid, if the potassium iodide was added gradually from a burette, the addition of 4 or 5 cubic centimeters gave a clear, light yellow liquid in which no free iodine could be proved either by starch or chloroform. As the amount of potassium iodide increases, the liquid gradually becomes orange until finally particles of iodine are precipitated out and accumulate until they reach the quantitative yield represented by the common equation :

$$5KI + HIO_3 + 5HCl = 3H_2O + 5KCl + 3I_2$$

These phenomena seem to indicate that the reaction takes place in two steps, giving first the iodine chloride, and then the decomposition of this by means of more potassium iodide setting free iodine. Even after solid particles of iodine appear in the liquid, starch paste is not colored blue, showing the well-known disturbing action of the chloride of iodine. That the intermediate product is essentially the *monochloride* of iodine instead of the *trichloride* may be inferred from the superior stability of the former in dilute solutions containing hydrochloric acid, since most authorities agree that the trichloride is completely broken up in dilute solutions into the monochloride, iodic acid and hydrochloric acid. If any trichloride were first formed and underwent this decomposition, the final form of the reaction would be the same as if the monochloride were the sole product. This inference was further confirmed by later results and by the following experiment.

The clear yellow liquid obtained by putting together 10 cubic centimeters of iodic acid, half that volume of hydrochloric acid, and 4 cubic centimeters of potassium iodide was agitated with benzene which is said to dissolve iodine trichloride with a dark cherry-red color.* The result was a barely perceptible pinkish tinge to the benzene, which left no appreciable residue on evaporation. After separating the benzene and adding ether, the color was quickly taken from the aqueous solution, and the ether became yellow and, on evaporation, left a considerable quantity of a volatile reddish-brown liquid. This

* Ladenburg, Handwörterbuch, v, 359.

experiment showed plainly that the essential product was iodine monochloride.

In three different ways I have tried to estimate the proportions in which iodic acid and potassium iodide unite in presence of an excess of the former and hydrochloric acid. The direct method of letting potassium iodide of known strength slowly into a mixture of the two acids and determining the first appearance of free iodine is difficult on account of the action of the iodine chloride on the blue iodide of starch which one would naturally use as an indicator. I have succeeded, however, in getting an approximate result, by taking out a drop of the liquid from time to time and testing on starch paper. With 5 cubic centimeters of iodic acid, 9·5 cubic centimeters of potassium iodide were added before there was any effect on the starch paper. This would indicate molecular proportions of iodic acid to potassium iodide as 1 : 1·9.

In the second method, 20 cubic centimeters of iodic acid, 10 of hydrochloric acid, and 4 of potassium iodide were put together, the resulting iodine chloride was extracted with ether and separated with a separating funnel. The aqueous solution containing free hydrochloric acid was then treated with an excess of potassium iodide and the amount of iodine set free determined, after neutralization, by alkaline arsenious acid. From this the iodic acid remaining in the solution after the extraction of the iodine chloride could be readily estimated, and the difference between this and the amount taken gave the amount used in the reaction. Three trials of this experiment gave the following results for the molecular proportions in which the iodic acid and potassium iodide unite in presence of hydrochloric acid while the iodic acid is in excess:

$$\left.\begin{array}{l} HIO_3 : KI \\ 1 : 2{\cdot}06 \\ 1 : 1{\cdot}99 \\ 1 : 1{\cdot}9 \end{array}\right\} \text{Average} = 1 : 1{\cdot}98$$

The third method consisted in putting together the reagents in the same proportions as above and then decomposing the iodine chloride with acid potassium carbonate and estimating the iodine set free by alkaline arsenious acid. According to Gay-Lussac, the reaction between iodine chloride and an alkali is represented thus:

$$6KOH + 5ICl = 5KCl + KIO_3 + 3H_2O + 2I_2$$

The iodine shown by the arsenious acid is then only $\frac{4}{5}$ of that in the iodine chloride. Making this correction and knowing the amount of iodine in the potassium iodide used, it becomes

an easy matter to determine the iodic acid which has contributed to the formation of the iodine chloride.

The following results were obtained:

$$\left.\begin{array}{l} HIO_3 : KI \\ 1 : 1{\cdot}92 \\ 1 : 2{\cdot}02 \end{array}\right\} \text{Average} = 1 : 1{\cdot}97$$

The three methods, then, agree fairly well in indicating two molecules of potassium iodide to one of iodic acid, a reaction which would be expressed by the following equation:

$$HIO_3 + 2KI + 5HCl = 3H_2O + 2KCl + 3ICl$$

The formation of iodine monochloride has thus been proved by three methods, two of which would be sufficient to establish the reaction. The first two methods are independent of the reaction between iodine monochloride and carbonated alkalies, while the third depends directly upon that reaction. Assuming the correctness of Gay-Lussac's equation, this third method may be taken simply as an additional way of proving what has been already sufficiently established in two different ways. On the other hand, considering the formation of iodine chloride sufficiently established by the two other methods, the last set of experiments may be used to discriminate between Gay-Lussac's and Grüneberg's reaction. The latter* states, without describing his work in detail, that he has found by many carefully repeated experiments that the action of alkaline carbonates on iodine monochloride gives potassium chloride and potassium chlorate, and *all* of the iodine is set free. My results, however, show the correctness of Gay-Lussac's equation, since it is only on the assumption that *four-fifths* of the iodine is set free that my third method of work gives results corresponding with those obtained in two other ways. Moreover, some iodine chloride was prepared by putting together potassium iodide, and an excess of iodic and hydrochloric acids, and extracting with ether, specially purified by standing over sodium bisulphite and distilling from sodium hydroxide. Portions of this ethereal solution were drawn off from a burette and treated with potassium iodide, and the iodine estimated by sodium thiosulphate. Similar portions were then treated with hydrogen potassium carbonate, and the iodine estimated by arsenious acid. Grüneberg's reaction would demand that one-half as much iodine should be set free in the latter case as in the former, instead of which only four-fifths of that amount was found, which is in direct agreement with Gay-Lussac's equation.

* Jour. für prakt. Chemie, lx, 172.

III. *Action of Iodine on Iodic acid in presence of Hydrochloric acid.*

Some light is thrown upon the reaction just established by the behavior of free iodine in a mixture of iodic and hydrochloric acids.

Although a solution of iodine in iodic acid turns starch blue, and also one of iodine in hydrochloric acid, if the solutions be mixed, the starch immediately loses its color, but regains it on the addition of alkaline carbonate. Also, if a colorless mixture of iodic and hydrochloric acids be taken, and aqueous iodine added gradually from a burette, the first effect of the addition is to make a colorless liquid in which the presence of iodine can be proved only upon addition of an alkaline carbonate. Further addition of the iodine gives a yellow liquid whose properties and reactions seem identical with that obtained by putting together iodic and hydrochloric acids and potassium iodide. This same liquid may be produced by allowing iodine to dissolve slowly in the cold in a mixture of dilute hydrochloric and iodic acids.

Apparently, then, the action of reducing agents is to set free iodine from the iodic acid, and this dissolves in a mixture of iodic and hydrochloric acids to form iodine chloride. Two experiments were made to determine the proportions in which the iodine and iodic acid unite in this reaction. Solid iodine, in carefully weighed quantity, was allowed to dissolve in a mixture of the acids, then the acid was neutralized with alkaline carbonate, and the iodine set free estimated by means of arsenious acid. The molecular proportions of iodic acid to iodine as found were as follows:

HIO_3	:	I
1	:	4·02
1	:	4·07

The same proportions were obtained by direct titration of iodic acid against a solution of iodine in hydrochloric acid of known strength. The operation was performed in a flask, a definite quantity of iodic acid being first introduced and then the solution of iodine added from a burette until, upon shaking the flask, the presence of free iodine was indicated by the characteristic color given to chloroform.

The molecular proportions found were:

HIO_3	:	I
1	:	4·02
1	:	4·06

These results, it will be seen, are in complete accordance with those obtained by the former method and indicate the following reaction:

$$HIO_3 + 2I_2 + 5HCl = 3H_2O + 5ICl$$

The equation obtained above for the reaction between iodic acid, potassium iodide, and hydrochloric acid, viz:

$$HIO_3 + 2KI + 5HCl = 3H_2O + 2KCl + 3ICl,$$

can be derived directly by a combination of the ordinary equation, in which iodine is set free,

$$[5KI + HIO_3 + 5HCl = 3H_2O + 5KCl + 3I_2]2,$$

with the equation just established,

$$[HIO_3 + 2I_2 + 5HCl = 3H_2O + 5ICl]3,$$

in which the iodine reacts upon iodic acid. This fact supports the assumption that the effect of a reducing agent upon an excess of iodic acid in presence of hydrochloric acid is to set free iodine which then dissolves in a mixture of the two acids to form iodine monochloride.

Iodine has apparently no effect upon either acid taken singly, and there is nothing in these experiments to show whether the action of the iodine on the iodic acid in the mixture of the two acids is in the first instance of an oxidizing or reducing nature. It may be that the iodic acid is first reduced to a lower oxide, as has been previously suggested, or that it is oxidized to periodic acid. The first condition is expressed in equations I, and the latter in equations II, from which it is seen that either assumption agrees with the equations just established.

I.
$$\left\{\begin{array}{l} 2HIO_3 + I_2 + 2HCl = I_2O_4 + 2H_2O + 2ICl \\ I_2O_4 + 3I_2 + 8HCl = 4H_2O + 8ICl \\ \text{Combined: } 2HIO_3 + 4I_2 + 10HCl = 10ICl + 6H_2O \end{array}\right\}$$

II.
$$\left\{\begin{array}{l} 2HIO_3 + 2H_2O + 2I_2 = 4HI + H_2O + I_2O_7 \\ I_2O_7 + 4HI + 10HCl = 7H_2O + 6ICl + 2Cl_2 \\ 2Cl_2 + 2I_2 = 4ICl \\ \text{Combined: } 2HIO_3 + 4I_2 + 10HCl = 10ICl + 6H_2O \end{array}\right\}$$

In any case it is evident that the mixture of iodine and iodic acid, both ordinarily oxidizing agents, is able to effect the decomposition of hydrochloric acid with the formation of iodine monochloride.

Art. XXII.—*The Stratigraphic Position of the Thomson* Slates;* by J. E. Spurr.†

Location and Extent of the Series.

The Thomson slates (St. Louis slates, Cloquet slates) are schistose or slaty rocks which occupy an extensive area in Eastern Minnesota. They afford continuous exposures along the St. Louis River, not far from Duluth, near Thomson, Carlton and Cloquet. Here they were first noted and described. They are in this region well cleaved, but possess evident and little-altered sedimentary characters. Further west they are found along and beyond the Mississippi River, in the vicinity of Little Falls. Here they have become schistose; they are often micaceous, staurolitic, hornblendic, or garnetiferous. Frequent outcrops have been found, demonstrating the continuity of the series between the St. Louis and the Mississippi. In a north and south line, the belt has already been shown, by the explorations of C. W. Hall, Merriam, Upham, and others, to extend, roughly speaking, from near the lower part of Mille Lacs to near the northern boundaries of Aitkin and Carlton counties. The writer has been able to trace these rocks as far north as T. 51–19, where an exposure is found which will be referred to later. This prolongs the known extent toward the north by 10 or 15 miles. The dimensions of the belt are thus about 100 miles east and west by 50 north and south, making an area of not far from 5000 square miles.

For the lithological variations from the simple cleaved slates, found within this area, we may quote from Irving:‡

"They include, among the slates, fine-grained graywacke-slates, clay-slates, sericitic quartz-slates, true quartzites, mica-slates (often hornblendic), staurolitic mica-slates (often garnetiferous), and hornblende schists; and among the eruptives, diabases, gabbros, and diorites, the latter presumably altered forms of diabase or gabbro."

Relations of the Thomson Series to the surrounding Rocks.

On three sides, south, east, and west, the general boundaries of the Thomson rocks are known. To the south and west lie

*To this series the name *St. Louis* has been applied by Irving, Sweet, Van Hise, and others. Inasmuch as this name, however, is already well established for a formation of quite different age, it has been thought best, in accordance with a suggestion of Professor H. S. Williams, to designate the Minnesota series in some other way. The term *Thomson*, therefore, which has already been used by Professor N. H. Winchell, has been adopted.

† Published by permission of the State Geologist of Minnesota.

‡ Fifth Annual Report U. S. Geol. Survey, p. 197.

areas of granite which have been referred to the Laurentian; and various post-Animikie (post-Huronian) sediments, as far up as the Cretaceous. To the east lie the Keweenawan rocks, chiefly igneous. To the north, however, the Thompson series is hid beneath a great thickness of drift which occupies a broad belt of country through which run the St. Louis and Mississippi rivers. Between the southern border of this drift mantle and the nearest known outcrops on the north (those of the Animikie of the Mesabi Range) the distance is about 40 miles.

Sketch of previous Correlations.

The Thomson rocks have been correlated, up to the present time, with the Animikie (the Upper Huronian). It is the object of this paper to suggest that there are no firm grounds for this correlation, and that they be referred rather to the Keewatin* (Lower Huronian). It will be advisable to inquire first into the reasons for which they have hitherto been assigned their place.

Irving† and Sweet‡ assigned these rocks to the Huronian in 1880. The reasons were mainly lithological. The Thomson (St. Louis) rocks presented the characters of an undoubted and little metamorphosed clastic series, especially in that part which alone was definitely known, i. e. the outcrops along the St. Louis River about Thomson. At that time there were recognized but three general horizons to which this series could be referred,—the Keweenawan, the Huronian, and the Laurentian. The Thomson (St. Louis) rocks were seen to underlie the Keweenawan, and to be cut by dikes of supposed Keweenawan age; and no rock of recognizable clastic characters could be referred to the Laurentian.

In the third annual report of the United States Geological Survey,§ Irving first hinted at the correlation of the "St. Louis slates" with the Animikie of northeastern Minnesota, as observed at that time around Gunflint Lake and Thunder Bay. He pointed out the general lithological resemblance between the two series, and noted the difference in that the "St. Louis slates" are cleaved. In the same report, however,‖ he suggested the correlation of the uncleaved Animikie slates with

* The terms Animikie and Keewatin are to be understood here in the sense in which they are employed by the Minnesota Survey; they are provincial designations, both of formations and of divisions of geological time, which correspond in general to the more comprehensive terms (Upper and Lower Huronian) used by the United States Survey.

† Geology of Wisconsin, III, p. 18.

‡ Op. cit., p. 339.

§ Copper-Bearing Rocks of Lake Superior, p. 162.

‖ Op. cit., p. 170.

the folded schists lying further north, and his descriptions and accompanying diagram clearly show that he included among these schists the larger part, if not the whole, of what we now know as Keewatin (Lower Huronian). In the fifth annual report* he first *confidently* assigned to the Thomson (St. Louis) series a place equivalent to that of the Animikie. A few pages later on,† however, he states that he hesitates to accept the idea of "a general unconformity between the flat-lying Animikie and an older series, including the gneiss and folded schists,"‡ but considers that, as suggested in the third annual report, there is a transition between the two, and that the schists are but the folded northward continuation of the Animikie. In the seventh annual report,§ he again refers to the St. Louis slates as Animikie; and here first hints as to what horizon of the Huronian they were believed by him to belong, i. e. the same as that of the upper slates of the Animikie series as represented upon the Mesabi Range.

If the writer understands correctly what has been done, the results may be briefly summed up as follows:

Irving, Sweet, N. H. Winchell,‖ and Hunt¶ assigned the Thomson (St. Louis) series to the Huronian, because of their undoubted detrital nature. No attempt was made at first to give them a definite horizon in this formation. Afterwards, however, Irving was led to conclude, from an examination of the Animikie rocks around Thunder Bay and Gunflint Lake and westward, that the upper slate member of the Animikie series of the Mesabi Range was the same as the slates along the St. Louis.

Subsequent writers have adopted this correlation, but no new arguments of value have been offered, either pro or con. Van Hise** has mentioned, as a circumstance tending to show their Upper Huronian (Animikie) age, the occurrence of ferruginous beds "in the northward extension of the St. Louis slates." No ores, however, have been found in the St. Louis slates; and if by the quoted phrase the ores of the Mesabi Range were meant, the occurrence of iron in the Animikie can have no bearing upon the correlation between the Ani-

* Archæan Formations of the Northwestern States, p. 196.

† Op. cit., p. 206.

‡ That is, an unconformity at the base of the Animikie; the Huronian unconformity as now understood. Irving recognized perfectly well an unconformity between the Huronian in general and the Laurentian, or fundamental complex of granites and gneisses.

§ Classification of Cambrian Formations, p. 422.

‖ Tenth Ann. Rep. Minnesota Geol. and Nat. Hist. Survey, p. 95; Eleventh Ann. Rep., pp. 169 and 170.

¶ Trans. Roy. Soc. Canada, vol. i, Sec. iv, 1883, p. 250.

** Tenth Ann. Rep. U. S. Geol. Survey, p. 461; Bulletin U. S. Geol. Survey, No. 86. Correlation papers, Archæan and Algonkian, p. 186.

mikie and the St. Louis series. The correlation, therefore, has rested entirely upon very broad lithological resemblances.

During the summer of 1893, the writer made an examination of the Western Mesabi region and south to the St. Louis slates, and came to suspect that there were no valid reasons for correlating the St. Louis series with the flat-lying Animikie of the Mesabi district. On the other hand, the evidence seemed rather in favor of correlation with the underlying schistose and slaty rocks, referred to the Keewatin in the same district.*

The Animikie Slates upon the Western Mesabi.

The slates which constitute the uppermost recognized member of the Animikie upon the Western Mesabi are usually soft, black, and carbonaceous; they dip gently southward to southeastward, and disappear beneath the heavy covering of drift. These rocks have been almost unaffected by altering dynamic forces since their deposition. There is no sharp crumpling, no cleavage or strongly-marked jointing; and very few fissure or gash-veins.

The Keewatin of the Western Mesabi.

The slates, with the lower members of the Animikie (the iron-bearing member and the quartzite), are in abrupt unconformity with the underlying rocks. Ordinarily, the underlying rock appears to be the granite of the Giant's Range, which has been supposed to be Laurentian; but in places a narrow belt of schists appears between the granite and the Animikie, and in T. 58–17 probable faulting has brought up a triangular area of schists 6 or 8 miles in its north and south extent. The appearance of this area and the attendant phenomena establishes two important facts: first, that the rocks on which the Animikie here rests are mainly schistose and slaty, instead of gneissic and granitic; and second, that the granite is intrusive into these cleaved rocks, and therefore cannot be regarded as Laurentian. The schists have been generally recognized as Keewatin.

The triangular upthrust area, which the writer has called the Virginia area,† has one side against the granite belt. Near the contact it is made up of mainly holocrystalline mica and horn-

* Professor N. H. Winchell was at one time in the field with the writer; and came to substantially the same conclusions. It should be stated, moreover, that Professor Winchell had for some time previous been skeptical as to the Animikie age of the Thomson series, and had even mapped a small part of the area as Keewatin, in a preliminary unpublished map exhibited at the World's Fair in 1893.

† Bulletin No. 10, Minn. Geol. and Nat. Hist. Survey, p. 17.

blende schists; but on going away from the granite area these are seen to have resulted from the metamorphic influence of the granite, for the rock soon changes into the common "green schist." This is a rock of which the original characters can be suspected, but ordinarily not readily determined. It is characterized by the development of sericite and kindred minerals along the schistosity planes. This green schist type occupies the central part of the area. In the southern part, however, near the apex of the triangle, the evidence of metamorphism decreases rapidly, and the rocks become mainly easily recognizable as detrital. Here are found what appear to be only slightly altered siliceous and clay-slates, and graywackes. In hand-specimen these Keewatin detritals often can hardly be distinguished from specimens of the overlying Animikie slates.

The Keewatin rocks possess a strongly-marked regional cleavage or schistosity, not far from vertical in hade, and nearly constant in trend,—averaging about N. 70° E. This is also nearly the direction of both the northern and southern contacts of the granite belt; and, in a general way, of the predominant rock-structure of a large part of the gneissic and schistose terranes lying further north, in northeastern Minnesota and Canada.* In short, it indicates the direction of movement of a regional disturbance which has affected a great area. This structure is still more pronounced in some of the country north of the Mesabi Range, and here granitic invasions and accompanying metamorphic action have also been more common; so that it seems that the seat of greatest disturbance lay north, rather than south of the Mesabi. This disturbance took place prior to Animikie time, for the Animikie rocks are unaffected by it.

The Animikie slates which overlie the Keewatin to the south, in T. 57–17, disappear beneath the drift within a few miles and are thence not traceable southward. On the east, their southward continuation is also hid by the overlying Keweenawan rocks, and on the west by the Cretaceous.

Physical characters of the Thomson Slates at Cloquet.

On passing south across the swamp-covered area, the first rocks which appear above the thinning mantle of drift are those of the Thomson series. The physical characters of the rock, as it appears typically on the St Louis River at Cloquet, near the place where it was first recognized, may be briefly described.

* Consult A. C. Lawson, Report on Geology of the Lake of the Woods Region, p. 21 et seq., Annual Report of the Geol and Nat. Hist. Survey of Canada, 1885.

The rock is in most places of evident sedimentary origin. It varies from a fine-grained slate, black, gray, or dark-green in color, to a siliceous slate or graywacke. Often small pebbles of detrital material, especially of quartz, may be found. The sedimentary structure is usually indicated by no parallel parting, but by the alternation of coarser and finer layers. An observation of these alternations shows that there is no constant dip and strike, but that the rocks have been much folded and crumpled. There are, however, persistent and continuous systems of cleavage. There are two principal sets of cleavage planes, one running from N. 80° E. to E. and W., and the second cutting the first at an angle of about 45°. The first cleavage is best developed, and gives the appearance of stratification to the formation. Where it is most strongly marked, there results a very perfect division of the rock into thin sheets; where both are well developed, the rock is cut up into fine rhombohedral blocks. In some of the coarser rocks, such as the graywacke, the structure is rather schistose than slaty. It is to be noted that neither of the cleavages corresponds to the bedding, or has any constant relation to it.

In places, where the rocks are cut by basic dikes, a third cleavage has been induced, extending for a few yards on either side of the dike, and running strictly parallel to its walls. This third cleavage cuts the other two, and near the dike almost obliterates them. The predominant cleavage or schistose structure, which runs a little north of east, has been very commonly described as stratification by previous writers. The minor parting, however, has been very generally recognized as a cleavage. Throughout the rock there are numerous irregular veins, chiefly of quartz.

This series was traced by the writer as far north as T. 51–19, near the St. Louis River. Here several specimens were taken from an outcrop (about N.W. $\frac{1}{4}$ S.W. $\frac{1}{4}$, Sec. 27). One phase is a dark green siliceous slate or quartzite; another is a fine-grained slate; a third is a silvery sericitic schist or slate. In the two last-named rocks what appears to be the original stratification may generally be distinguished; and in the specimens taken this structure runs nearly at right angles with the cleavage. It is not so plain, however, as ten miles further south. There was found at this place only one cleavage or schistosity (for in different zones it appeared as each) in the rock. This corresponded in general with the main cleavage at Cloquet, with a steep hade, and a trend between N. 60° E. and N. 80° E.

Grounds for Correlation.

We may now suggest grounds for correlating the Thomson series with the Keewatin of the Mesabi Range rather than with the Animikie of that district.

1. *Lithological.*—Since the basis on which the Thomson slates have been correlated with the Animikie was purely lithological, we will first present the same argument for correlation with the Keewatin; and it appears that the grounds for the latter are much stronger.

The slates as seen about Cloquet resemble very closely the slates of the southern part of the Virginia area. Almost every phase of the Cloquet rocks can be duplicated in this Keewatin district. They differ only in that the St. Louis rocks are traversed by a minor transverse cleavage. But the resemblance of the northern part of the known St. Louis rocks, those in T. 51–19, described above, to those of the Virginia area is complete. Here not only the little altered detrital phases are duplicated, but to a certain extent some of the less altered schistose rocks, such as the sericitic slate already described. Moreover, all the specimens have the peculiar greenish tint which is usual in the Keewatin rocks (the "green schists") and is a distinctive mark as compared with the dead black of the unaltered carbonaceous Animikie slates.

In the region further west, especially in the vicinity of the Mississippi River, the Thomson series becomes in part crystalline, having changed into sericitic, micaceous, hornblendic, staurolitic, or garnetiferous schists. These phases, which occupy a considerable portion of the series, correspond exactly to the "green schists" and crystalline schists of the Keewatin in the Mesabi district.

2. *Dynamical.*—One of the greatest differences between the least altered Keewatin rock of the Virginia area and the Animikie slates in the vicinity is the presence of the steeply dipping regional cleavage, which has an average trend of about N. 70° E. This, as has already been noted, marks a distinctively pre-Animikie disturbance. In the Cloquet rocks there is a strongly developed cleavage, nearly constant, running a little north of east (averaging perhaps N. 85° E.) and so having approximately the same trend as that of the Mesabi district. In T. 51–19, ten miles further north, the same strong cleavage, with nearly the same direction, was found, and the transverse cleavage which is seen at Cloquet was not observed. From here to the first rock exposures, upon the Mesabi Range, the distance is about 40 miles; and here, as before observed, there is no sign of disturbance in the Animikie rocks, but the Keewatin exhibits the same cleavage, as well as the same lithological peculiarities.

It may be allowed to suspect, then, that the cleavage of the Thomson series was developed at the same time and by the same forces as that of the Mesabi Range and as the corresponding structures which are found further north, in Minnesota and Canada. If this be the case, the Thomson series must be put below the unconformity exhibited upon the Mesabi, and provisionally correlated with the Keewatin. The secondary cleavage shown in the Thomson slates, as at Cloquet, may for the present be supposed to be more local, and to have had its cause near by,—perhaps connected with the advent of some of the larger masses of igneous Keweenawan rock, as we have noted that the rare third cleavage accompanied the introduction of the narrow dikes.

We must also take into account the considerable folding which the Thomson series has undergone, as distinguished from the undisturbed condition of the Animikie. In this respect also it resembles more the Keewatin. The occurrence in the Thomson slates of many veins of quartz and the generally indurated appearance of the rocks accords with the appearance of Mesabi Keewatin, and suggests that the beds have been deeply buried.

The Animikie-Keweenawan Unconformity.

If it shall be finally considered that this suggested correlation is correct, we shall appear to have in this region Keewatin strata directly overlaid by the Keweenawan rocks which are exposed in great quantities a little further east. If we believe in the original extension of the Animikie sediments over the whole Lake Superior basin, it will follow from this correlation that the erosion interval between the Animikie and the Keweenawan was very great.

Minneapolis, May 3, 1894.

Art. XXIII.—*The Generation of Chlorine for Laboratory Purposes;* by F. A. Gooch and D. Albert Kreider.

[Contributions from the Kent Chemical Laboratory of Yale College—XXXIII.]

That chlorine may be generated in a state of greater or less purity, variable with the conditions of evolution, by the action of hydrochloric acid upon potassium chlorate has been shown by Pebal* and Schacherl,† but the application of this fact to the practical generation of chlorine for the purposes of the

* Ann. der Chem., clxxvii, 1. † Ibid, clxxxii, 197.

laboratory has not to our knowledge been proposed. The desirability of an automatic generator from which an abundant flow of chlorine gas may be drawn at will or shut off without danger or inconvenience has led us to a study of the conditions most favorable to the safe evolution of chlorine by the action of the chlorate.

Pebal* showed that the gas evolved at ordinary temperatures from a mixture of potassium chlorate and sodium chloride acted upon by sulphuric acid diluted with twice its volume of water consists of chlorine and chlorine dioxide in nearly equal proportions. Schacherl† found that when potassium chlorate was acted upon by hydrochloric acid diluted with twice its own volume of water the yield of chlorine was about 46 per cent or 57 per cent of the mixed gases according as the chlorate was granular or in fine powder; that hydrochloric acid of half-strength yielded a gas containing nearly 60 per cent of chlorine, and that the proportion of chlorine rose nearly to 68 per cent when the gas was passed through concentrated hydrochloric acid and then washed with water; that the chlorate when acted upon by the strongest hydrochloric acid cooled to 0° C. and then warmed only enough to start the action yielded a gas carrying 87 per cent of chlorine; and that when a solution of potassium chlorate was permitted to flow into hot strong hydrochloric acid the free chlorine constituted nearly 75 per cent of the mixture. So it appears that the highest yield of chlorine resulted when the solution of the chlorate entered gradually the hot strong acid—a condition not easily attained in an automatic generator.

The fact that chlorine dioxide is so easily decomposed by heat into chlorine and oxygen naturally suggests the possibility of increasing the proportion of chlorine evolved in the first instance by working at the highest temperatures practically attainable under the conditions. In order, however, to secure a temperature approaching the boiling point of water it is necessary to reduce somewhat the strength of the hydrochloric acid acting (in order to avoid the evolution of hydrochloric acid gas and the consequent interference with the regular automatic action of the generator), thus sacrificing the advantage naturally attending the use of acid of the highest degree of concentration. Upon experiment we find that acid of half-strength (sp. gr. 1·10) can be made to yield a very satisfactory proportion of chlorine. We have employed in our work potassium chlorate fused (best in platinum) and cast in sticks or broken into coarse lumps. A small Kipp's apparatus, holding about a half-liter of liquid in the two lower chambers, makes a convenient generator, and the requisite temperature

* Loc. cit. † Loc. cit.

may be secured by wrapping the two lower chambers with flexible metallic tubing through which steam is driven, or, with equal convenience, by simply standing the whole apparatus in heated water. When the simple precaution is taken to heat the acid to 60° or 70° C. before allowing it to come slowly into contact with the fused chlorate no difficulty whatever is met with in the practical automatic working of the generator; but if cold acid is permitted to act upon the chlorate it becomes charged more or less with the chlorine dioxide and a subsequent rise of temperature may cause dissociation of the explosive gas with sufficient suddenness to expel the liquid from the generator with considerable violence. The gas evolved directly from the generator is never pure chlorine. To determine the relative proportions of chlorine and chlorine dioxide (the sole products of the action according to Pebal) the gas as it issued from the generator was passed through two pipettes fitted with glass stopcocks and joined to one another. After allowing a reasonable time for the complete expulsion of air from the pipettes the stopcocks were closed, and the pipettes were disconnected from one another and from the generator. The gas contained in one of the pipettes was slowly forced by means of carbon dioxide through a solution of potassium iodide; that in the second pipette was driven slowly by means of carbon dioxide through a hard glass tube filled with asbestos and heated to redness by a Bunsen burner, and then passed through a solution of potassium iodide. The iodine set free in each case was determined in the acidified solution by standard sodium thiosulphate, and the difference in the amounts of iodine found was attributed to the action of the oxygen of the chlorine dioxide. It was assumed that the gas filling the pipettes ranged in line was homogeneously distributed, and this assumption is probably nearly enough true for the purpose of this discussion. The temperature of the acid in the generator was determined by inserting a thermometer in the lowest chamber of the generator, so that the indication for the point of action is only approximate.

In two experiments made with acid of half strength and at indicated temperatures of 80° and 81° the chlorine in the gas amounted to 81·6 per cent and 84 per cent respectively of the mixture. A comparison experiment made with the strongest acid heated to 50°—the highest temperature attainable without evolution of the hydrochloric acid gas—the yield of chlorine was 77·3 per cent. It is evident that the acid of half strength acting at 80° is productive of a more favorable yield than the strongest acid at 50°.

Temperatures very much higher than those employed can hardly be secured continually under the conditions of work,

and yet it is plain that a considerable amount of the oxide still accompanied the chlorine. We made the attempt, therefore, to accomplish the destruction of the oxide by passing the mixed gases as they issued from the generator through a small wash-bottle containing a hot saturated solution of manganous chloride in strong hydrochloric acid, making use of a device previously employed in this laboratory for the decomposition of nitric acid and chloric acid.* The results of several experiments conducted in this manner are recorded in the accompanying statement. The gas after leaving the manganous chloride passed through a small wash-bottle filled with water, was dried by calcium chloride, and collected in the pipettes arranged in train, and analyzed by the method previously described.

Strength of hydrochloric acid.	Temperature of acid.	Temperature of the solution of $MnCl_2$.	Bubbles of gas passing the wash-bottle per second.	Per cent of chlorine.
Sp. gr. 1·1	83°	90°	5–6	87·5
" "	83	90	4–6	89·5
" "	70–80°	90	1–2	96·4
" "	87·5	90	3	98·6
" "	83	90	3	96·9

It is evident from these figures that the efficiency of the manganous chloride is considerable and naturally most manifest when the current of gas is slow. Indeed, during the passage of gas through the manganous salt small bubbles of chlorine are evolved from the entire surface of the liquid. The washed gas is pure enough for most laboratory purposes, but if chlorine perfectly free from chlorine oxide is desired it may be obtained by passing the washed gas through a hard glass tube filled with asbestos and heated by a Bunsen flame.

In the exceptional cases in which the ignition tube is used it is well to keep in mind the fact that in starting the generator the acid should not be thrown in too great quantity upon the chlorate at first lest an unusually large proportion of the dioxide be liberated, which may cause a slight explosion in the ignition tube. Should such be the case, however, the liquid in the wash-bottle will prevent the extension of the explosion to the gas in the generator proper, and the insertion of the wash-bottle should never be omitted when the ignition tube is to be put to use. So long as it is kept hot we have never found the apparatus other than perfectly manageable, safe, and automatic in action.

Inasmuch as a single gram of potassium chlorate produces approximately a half-liter of chlorine, and a cubic centimeter

* This Journal, xliv, 117; xlvi, 231.

more than a liter, it is obvious that a very compact generator may be capable of delivering a considerable supply of the gas, and we have found the diminutive apparatus shown in the accompanying figure an exceedingly convenient addition to the furnishings of the laboratory table when chlorine is needed frequently and in small amounts. This little generator is easily made of a side-neck test tube, funnel tube, stopper, glass stopcock, and flask. The upper chamber of the test tube, which is constricted near the middle, holds easily ten grams of the fused chlorate, and when the outer flask is filled with hot water the automatic action is satisfactory for a considerable length of time. A little wash-bottle containing a hot saturated solution of manganous chloride in strong hydrochloric acid is a desirable addition when a purer gas is needed than that delivered directly from the generator, and the attachment of the ignition tube makes it possible to secure the chlorine entirely free from chlorine oxide, though carrying, of course, some free oxygen.

SCIENTIFIC INTELLIGENCE.

I. Geology and Mineralogy.

1. *Geologic Atlas of the United States, Livingston Folio, Montana* (folio No. 1), *U. S. Geol. Surv.*, J. W. Powell, Director. Washington, 1894, Ex. 2° 2 pp. text, 4 maps 1 pl.—Those who are interested in the progress of the work performed by the Geological Survey will be pleased to see this folio. Some small preliminary and experimental editions of similar sheets have been previously published, but this is the first folio issued in complete form and for the public. It marks in a certain way the beginning of the final results for which the Survey was organized. There are few, save those who have watched the progress of the organization from its inception, who realize the vast amount of careful and laborious work necessary to produce the present folio.

The area chosen for illustration upon the first sheet of the geologic and topographic atlas, has been well selected to display the high order of scientific work the survey is doing. It lies between 110° and 111° west and 45° and 46° north; and Livingston, situated on the Northern Pacific R. R. and the Yellowstone River, and within these boundaries, has given its name to

the folio. The area therefore, lies immediately north of the Yellowstone National Park. The southeastern portion comprises an elevated block of mountains called the Snowies, chiefly of Archæan formation but cut by intrusions of igneous rocks and covered in part by enomerous extensions of lavas and tuffs. Around the western and northern slopes of this great mass winds the Yellowstone river in an open valley. The Paleozoic formations lie tilted up against its flanks, while the Mesozoic are partly upturned and partly occupy in more horizontal position the open valley of the Yellowstone. The western edge is defined by the slopes of the Gallatin Range, chiefly composed of igneous extrusive masses, and the Bridger Range of Archæan and Paleozoic upturned rocks. To the north the line passes through the southern flanks of the Crazy Mt. massive, Cretaceous? strata injected with igneous masses of which only the singularly vast and intricate system of radiating dikes shows on the map.

Thus there is great variety both in topographic form and in the range of geological formations, affording an excellent opportunity for the display of the varied resources of the survey in geological work and map-making.

The folio contains first two pages of text explanatory of the geography, topography and geology both scientific and economic. Then follows a topographic map with the elevations given by contours and on a scale of four miles to the inch. These maps produced by the survey, often in conjunction with the States, have become tolerably familiar to the public of late years. When the amount of time and money available for their production is taken into consideration they are wonderfully accurate, while the mechanical execution is extremely perfect and beautiful. The triangulation and topography of the Livingston sheet are by Messrs. RENSHAWE, DOUGLAS, TWEEDY and LEFFINGWELL, under the supervision of Mr. GANNETT, chief topographer and Mr. THOMPSON, chief geographer in charge.

The geological maps in colors that follow are three in number, the first giving the areal geology on the topographic base, the second devoted to economic geology is similar but with the coal-bearing strata strongly accentuated, while the third on a flat base gives only the main geologic areas and is cut by sections giving the geological structure in detail.

These are followed by a plate giving the columnar section of the sedimentary formations accompanied by full notes and details.

The geological portion of the work has been under the charge of ARNOLD HAGUE, the geology in the field having been done by Messrs. J. P. IDDINGS and W. H. WEED. The names of these specialists are sufficient to indicate the clear and excellent manner in which the survey has been carried out, and the maps themselves give the best evidence of the careful and painstaking work that has been put upon them both in the field and in the office.

The pleasing tones and patterns and the artistic combinations of colors of these maps deserve a separate word of commenda-

tion. In this they are in striking contrast to the generality of geological maps, such for instance as the new geological atlas of Germany, issued at Gotha under the supervision of Prof. LEPSIUS, whose glaring colors and sharp contrasts offend the eye. In only one point does it appear that the Livingston map could have been improved. In the areal geology sheet the tone of the color selected for Archæan is too dark, making it difficult to see the contour lines and to study the geology in connection with the relief form. The same may be said of the areas of basic andesitic breccia. On the other hand the tone of the same color employed for the corresponding areas on the economic sheet is all that could be desired, in this respect.

The use of yellow instead of the conventional tones of red to designate the igneous rocks will appear novel to many, but it must be admitted that it adds to the artistic beauty of the map and defines the areas with great clearness. L. V. P.

2. *Relation of double refraction to Soda in Hornblende;* by ALFRED C. LANE. (Communicated).—I find that the following law fits not only my own observations on hornblende, but also such few indications as I can find in the literature,—

$$n = 90/17\ (0{\cdot}012 - b)$$

where n is the amount of soda contained, and b the refraction of the orthopinacoidal (100) section; b to be considered negative, as is natural, whenever the refraction for the vertical axis is less than for the lateral. That this double refraction should be dependent on the amount of soda is rendered less surprising by the fact that with the increase of soda there is generally also a progressive absorption of the red end of the spectrum in the same section.

If the amphiboles contained but two molecules, one containing soda and the other not, a law of the above form must theoretically be true as a first approximation,* but I am rather surprised that it seems to apply so widely as it does in so complex a group. It is to be remembered, however, that for any two molecules having the same axial plane there will be a couple of sections at right angles to the axial plane which will have the same double refraction in each molecule, and therefore will not vary in double refraction in isomorphous mixtures of the two. It is probably true therefore that for the commoner and more important non-sodiferous molecules the orthopinacoidal double refractions are nearly the same. This is not true, however, for the brown Bohemian hornblende described by Levy and Lacroix, and this is the only case that I know of where the law can be said definitely to fail. But observations are few, and the main object of this communication is to call the attention of fellow-workers to the subject, and urge upon all those who make hornblende analyses to observe this double refraction. Or, if they will exchange material with the writer he will be very much obliged.

* Pockels, Neues Jahrbuch, 1893, Beilage Band viii, p. 135.

3. *A new locality for Silurian Limestone in Northern Michigan;* by A. E. SEAMAN. (Communicated).—In view of the fact that much has been written about Limestone Mountain, west of Baraga, and as it has been stated, that it is the only outcrop of Silurian limestone in Michigan west of Keweenaw Bay, I think the knowledge of a new locality will be of interest to the readers of your magazine.

Early last winter Mr. Abner Sherman of Houghton, brought to my office at the Mining School, a specimen of limestone which, he said, was taken from an outcrop near the center of Section 7, T. 51, R. 34. Having some doubt as to the limestone being in place, I decided to visit the location in order to verify the observations of Mr. Sherman. June 4th I started for the locality, in company with Drs. Hubbard and Lane, of the Geological Survey, and Mr. L. A. Wright, of the Mining School.

The limestone was found to occupy a synclinal basin, the greater part of which lies south of the center of the aforesaid section. The major axis of the fold lies about north 30° east, and the dip varies from 3° to 28°, the steeper dip being northwesterly. The strata exposed will approximate a hundred feet in thickness, and form bluffs, which in places, rise precipitously to the height of sixty-five feet. These bluffs form a higher and a lower terrace, which can be traced for about five hundred paces. The Lake Superior sandstone was seen to dip in conformity with the limestone, the two rocks being separated by only a few feet of talus.

The fossils collected are characteristic of the Lower Silurian (Trenton). Besides brachiopods, lamellibranchs, gasteropods, corals, crinoids, bryozoa, etc., I found the pygidium of one trilobite.

Advantage of the occasion was taken to visit Limestone Mt. on sections 13, 14, 23 and 24, T. 51, R. 35. Here near the bottom of the limestone series, fossils were collected which correspond with those above mentioned from section 7. Higher up in the series were found characteristic Upper Silurian fossils, probably Niagara. Our observations thus verify those of Mr. W. L. Honnold,* who three years ago, collected Niagara fossils from this location. The finding of limestone outcrops on section 7, makes it quite probable that careful search will reveal others capping high synclinal hills in the sandstone area.

Michigan Mining School, Houghton, Mich., June 18, 1894.

4. *Etude sur la détermination des Feldspaths dans les plaques minces;* by A. MICHEL LÉVY (Baudry), Paris, 1894, 8°, 70 pp. 8 pl. in col.—The appearance of this work is another token of the excellence of the methods of research with which petrography is being supplied.

We are already indebted to the author for many valuable researches on the relations between the optical and crystallographic properties of the feldspar group with special reference to their use

* This Journal, xlii, p. 170, 171, 1891.

in microscopical petrography. In the present case, the author has in addition extended the recent works of Federov and Becke, added new methods of his own and produced a volume which will be gratefully received by working petrologists. It is now possible on a single section of a microlitic soda lime feldspar to determine within close boundaries not only its chemical composition but its orientation as well. It is thus to be hoped that the indefinite word plagioclase will henceforth be used in much restricted manner.

The volume is embellished by eight beautiful plates in color showing in stereographic projection all the relations between the optical properties of the soda lime feldspars and their crystal form, thus adding greatly to its value. L. V. P.

Obituary.

George Huntington Williams died at Utica, N. Y., on the 12th of July, at the age of 38. He was born at Utica, and graduated from the Utica Free Academy, entered Amherst College in 1874 and took his first degree with the class of 1878. While in college he caught his enthusiasm for geology from his Professor, B. K. Emerson, and spent a year in graduate studies at Amherst. He then went to Berlin, where he perfected his knowledge of German, and to Heidelberg where he was a devoted pupil of Rosenbusch and took the Ph.D. degree in 1882. In the following year he became a fellow in Johns Hopkins University where he was appointed Professor of Inorganic Geology in 1885, which position he still held at the time of his death.

Petrography and Crystallography were the special departments of geology which he cultivated, and his text-book on Crystallography is a lucid exposition of the methods of research in this line. At the time of his death he was at work on a treatise on the Microscopic Structure of American Crystalline rocks. He was one of the best authorities on these subjects in America, and served as one of the judges of award in the department of Mineralogy at the Columbian Exposition. His untiring devotion last summer at Chicago to the duties thus put upon him, it is feared may have laid the foundation of the disease which overcame his otherwise vigorous constitution. Professor Williams was an attractive teacher and had a peculiarly pleasing manner in both private conversation and public address, and the animated and clear descriptions he gave of even the most technical subjects went far to interest his hearers in any topic he chose to speak upon. His broad education, attractive personal qualities and thorough acquaintance with the facts of his science gave him a prominent place among his fellows, and although still a young man he was rapidly rising to honor and fame. His loss will be keenly felt by all who knew him.

APPENDIX.

Art. XXIV.—*Miocene Artiodactyles from the Eastern Miohippus Beds;* by O. C. Marsh.

In recent numbers of this Journal, the writer has described various ungulate mammals from the upper Miocene of South Dakota and adjoining regions.* These were artiodactyles mainly, and of them the larger forms were related more or less closely to the genus *Anthracotherium*, established by Cuvier in 1822. These forms prove, on further study, to be more numerous and important in the horizon where *Protoceras* was found, or in the eastern Miohippus beds, than was at first suspected, and some additional specimens are described briefly and figured in the present article.

Heptacodon gibbiceps, sp. nov.

The type specimen of the present species is a skull in good preservation, except the posterior part, which is lost. The portion preserved fortunately affords a number of characters sufficient to separate the genus from allied forms of the same horizon, which will be discussed later.

The facial portion of this skull is strongly rounded above, especially in the frontal region, and this has suggested the specific name. The orbits are large, and not closed behind, although limited posteriorly by strong processes above and below. There is no antorbital depression, and the lachrymal foramen is inside the orbit. The nasals are elongate, narrow in front, and widely expanded behind where they join the frontals. They touch the lachrymals, thus separating the maxillaries from the frontals.

* This Journal, vol. xlvii, p. 409, May, 1894; and vol. xlviii, p. 91, July, 1894. See also, vol. xli, p. 81, January, 1891; vol. xlvi, p. 407, plate vii, November, 1893; and vol. xxxix, p. 524, June, 1890.

There were in all forty-four teeth. Three incisors were present on each side above, and there is a diastema behind the last one. The upper canine was large, and directed well forward and outward. There is no diastema behind the canine, and the four premolars form with the true molars a continuous series. The first and second premolars are secant, the third is subtriangular in outline, while the fourth has its crown composed of one external cusp and one internal cone. The upper molars conform strictly to the pattern of the type specimen on which the genus was based. A figure of this tooth and one of the corresponding molar of the present specimen are given below, natural size, in cuts 1 and 2.

1.

2.

FIGURE 1.—Last upper molar of *Heptacodon curtus*, Marsh; left side; seen from below.

FIGURE 2.—The same tooth of *Heptacodon gibbiceps*, Marsh.

Both figures are natural size.

The posterior nares open opposite the middle of the last upper molars. The anterior palatine foramina appear to be confluent, forming together a heart-shaped aperture, which may in part be due to injury.

This type specimen indicates an animal about the size of a wild boar.

Elomeryx armatus, gen. nov.

The specimen described in the last number of this Journal as *Heptacodon armatus* proves on examination to belong to a distinct genus, which may be called *Elomeryx*. Of this genus, two species are now known. Some of the main characters are as follows:—

The skull is elongate, with the facial part quite narrow. The frontal region between the orbits is flat or even concave. The orbits are very small, and not closed behind. There is no lachrymal fossa. The anterior narial opening is large, and the snout broad.

There are the usual forty-four teeth. The upper incisors diverge, and have short, compressed crowns. The upper canine is very large and dependent. It is oval in outline near its base, but compressed below, with a serrated posterior edge; a feature not before observed in ungulate mammals.

3.

4.

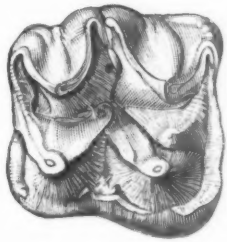

FIGURE 3.—Left upper canine of *Elomeryx armatus*, Marsh; outer view.
FIGURE 4.—Last upper molar of same species; right side; seen from below.
Both figures are natural size.

There is a long diastema behind the canine. The premolars and molars form a close series. An upper canine and last molar of the type species are shown above, natural size, in figures 3 and 4, and the upper molars of a new smaller species, in figure 5 below.

5.

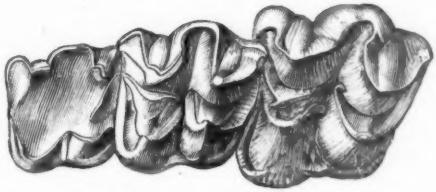

FIGURE 5.—Upper molars of *Elomeryx mitis*, Marsh; left side; seen from below.
Natural size.

The posterior nares are placed well behind the molar series, much as in existing swine. There is a postglenoid process, and a long paroccipital. The type species has a small auditorial bulla, and the other, a larger one. The zygomatic arch is slender, and curved well outward. The temporal fossæ are large, and separated above by a narrow sagittal crest. The brain was well developed. The type specimen of *E. armatus* indicates an animal about the size of a large deer.

Octacodon valens.

In addition to the two genera above described, there is a third, closely allied to them apparently, which is now known from various remains found in the same horizon. These remains may for the present be provisionally placed in the genus *Octacodon*, a typical upper molar of which is shown below, figure 6. One character seen in the teeth of this genus is the short crowns of the premolars and molars and the low cusps and cones of which they are composed. This feature will at once distinguish the teeth from those known as *Hyopotamus*,* found in the same region. In the latter forms, the elevations of the crowns are especially prominent and pointed, as shown in the molar represented in figure 7.

6. 7.

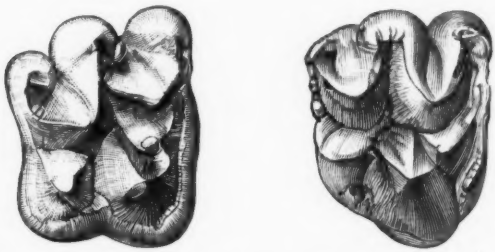

FIGURE 6.—Last right upper molar of *Octacodon valens*, Marsh; seen from below.
FIGURE 7.—The same tooth of *Ancodus* (*Hyopotamus*) *deflectus*, Marsh.
Both figures are natural size.

The position of the first premolar is another character of importance. In *Heptacodon* and *Elomeryx*, this tooth is situated close to the second premolar, but in the specimens here referred to the present genus, it is separated from both the canine and the second premolar by a well-marked diastema. None of these genera have the dependent process on the lower jaw which is characteristic of *Anthracotherium*. The nearer relations of these various allied forms will be discussed by the writer in a later communication.

Yale University Museum, New Haven, Conn., July 19, 1894.

* The generic name *Ancodus*, Pomel, has priority over *Hyopotamus*, Owen, and the latter must be regarded as a synonym. The name of the family therefore should be *Ancodontidæ*.

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